NISTIR 6198

U.S. DEPARTMENT OF COMMERCE
Technology Administration
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Office of Applied Economics
Building and Fire Research Laboratory
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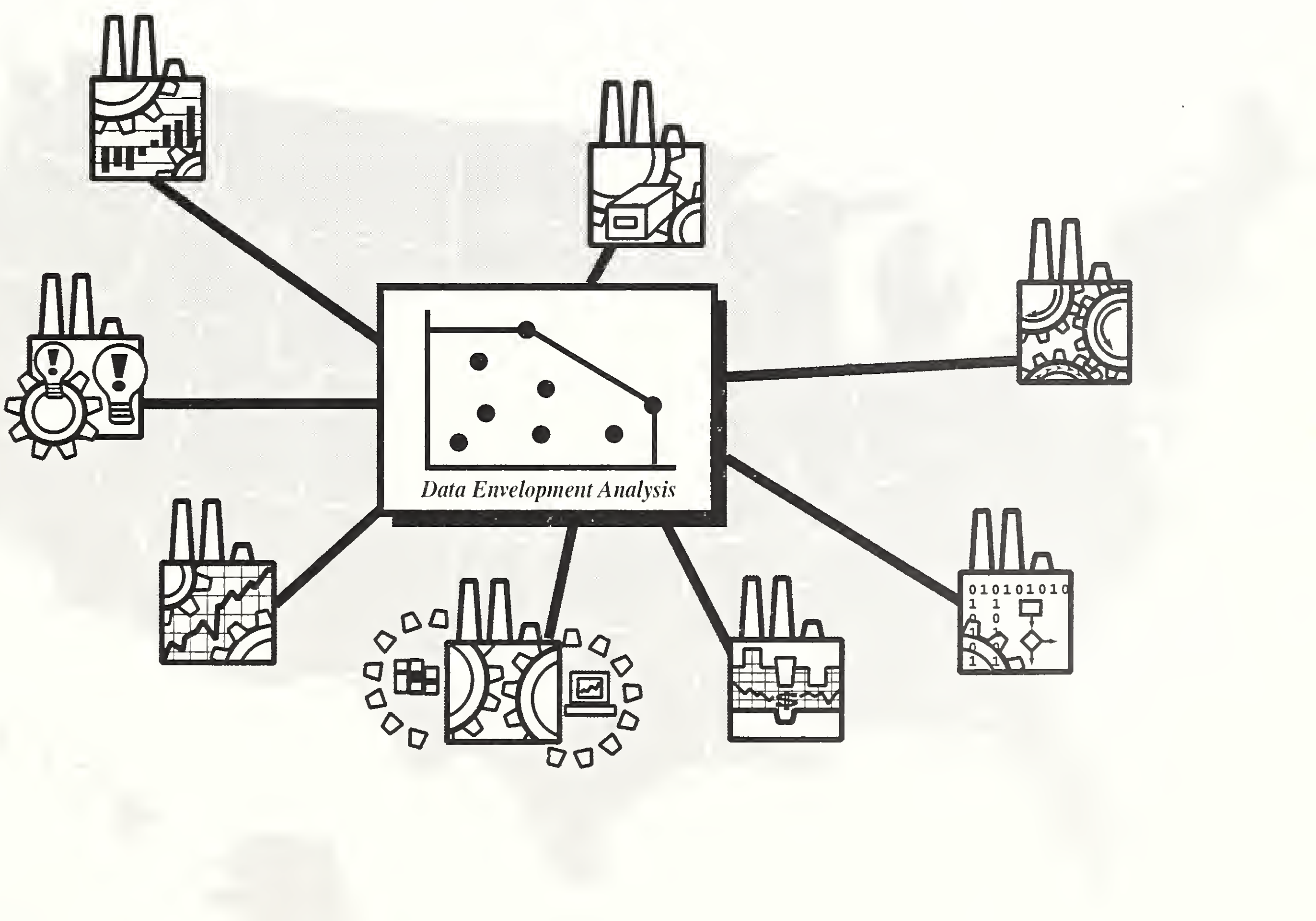
Using Data Envelopment Analysis to Assess Performance of Manufacturing Extension Centers

Robert E. Chapman



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U.S. DEPARTMENT OF COMMERCE
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Abstract

The purpose of this report is threefold. First, it describes how Data Envelopment Analysis (DEA) may be applied to assist the Manufacturing Extension Partnership (MEP) Program and its network of Manufacturing Extension Centers (MECs) in assessing performance. DEA is an approach to performance assessment which uses linear programming and principles of frontier analysis. DEA provides an integrated method for performance assessment which computes a single measure of performance based on multiple outputs and inputs. To accomplish the first purpose, the theory and methodology of DEA are related to MEP operating data focused on the twin informational needs of continuous improvement and program accountability. These operating data include both inputs--staff and financial resources--and outputs--types and levels of services rendered. The second purpose is to apply data from the current NIST/MEP Management Information Reporting System to illustrate ways in which DEA can help MEP headquarters and its network of MECs to measure their performance. Operating data from 51 MECs are analyzed via a series of performance assessment models; each model is a unique combination of inputs and outputs. The third purpose is to stimulate feedback and discussion among those engaged in MEP performance assessment. DEA provides a method which MEP and its network of MECs can use jointly to make sense of the multi-dimensional nature of MEC performance data. With this report MEP is in a position to initiate further uses of DEA which will prove beneficial to both the MECs and the national program.

Key Words

competitiveness; data envelopment analysis; economic analysis; economic impacts; extension services; linear programming; manufacturing; performance assessment; program evaluation.

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Table of Contents

List of Figures

List of Tables

1. Introduction

1.1. Background

The pressures of competing in the global marketplace are affecting nearly every U.S. business. Now more than ever, U.S. businesses are finding that they must continuously improve their products and services if they are to survive and prosper. These competitive pressures are especially high for more than 370,000 U.S. manufacturers with fewer than 500 employees. These small and medium-sized manufacturers account for about 95 percent of all U.S. manufacturing establishments and about half of the nation's manufacturing capacity.[1]

NIST's Manufacturing Extension Partnership (MEP) Program is a nationwide network of affiliated Manufacturing Extension Centers (MECs) dedicated to helping small and medium-sized manufacturers improve their competitiveness by adopting modern technologies and production techniques. Each MEC is a partnership typically involving federal, state, and local governments; industry; educational institutions; and other sources of expertise, information, and funding support.[2]

Smaller manufacturers face some unique barriers that hinder their ability to successfully modernize their operations. The MEP links these manufacturers with information and experienced manufacturing experts to help them improve their abilities to compete. The MECs serve as a conduit for these manufacturers to in-house manufacturing experts, as well as, private consultants, vendors, universities, federal agencies, and other sources of technical help.

MEP also helps foster a more unified network by working with MECs to identify and coordinate the services, technology, and information needed at a national scale. MEP is developing a uniform system to help MECs evaluate and continuously improve the success of services they deliver. This report is intended to support these efforts.

1.2. Purpose

The purpose of this report is threefold. First, it describes how Data Envelopment Analysis (DEA) may be applied to assist the Manufacturing Extension Partnership (MEP) Program and its network of Manufacturing Extension Centers (MECs) in assessing performance. Specifically, the report provides an introduction to the theory and methodology of DEA. For a more thorough and detailed description of DEA, see the

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[1] National Institute of Standards and Technology (NIST). 1995. *Technology for Business*. NIST Special Publication 875. Gaithersburg, MD: National Institute of Standards and Technology.

[2] Readers interested in learning more about the MEP Program are encouraged to browse the Manufacturing Extension Partnership Source, an electronic resource for MEP-affiliated MECs and the manufacturing community nationwide (the URL Address for the electronic resource is: http://www.mep.nist.gov/).

excellent book by Norman and Stoker.[3] For a concise theoretical discussion of DEA, see the review article by Boussofiane *et al*.[4] To accomplish the first purpose, the theory and methodology of DEA are related to MEP operating data focused on the twin informational needs of continuous improvement and program accountability. These operating data include both inputs--staff and financial resources--and outputs--types and levels of services rendered.

Second, the report uses data from the NIST/MEP Management Information Reporting System to illustrate ways in which DEA can help MEP headquarters and its network of MECs to measure their performance. To accomplish the second purpose, operating data from 51 MECs are analyzed via a series of performance assessment models. Each model is a unique combination of inputs and outputs (i.e., variables). The models illustrate how changing the set of inputs and/or outputs--adding a new variable or disaggregating an existing one--affects a particular MEC's performance.

Third, this report is intended to stimulate feedback and discussion among those engaged in MEP performance assessment. DEA provides a method which MEP and its network of MECs can use jointly to make sense of the multi-dimensional nature of MEC performance data. While DEA is only one of several MEP approaches to performance assessment, it is a particularly flexible and interactive one. With this report MEP is in a position to initiate further uses of DEA which will prove beneficial to both the MECs and the national program.

1.3. Scope and Approach

This report has four chapters and two appendices in addition to the Introduction. Chapter 2 introduces DEA, describes how DEA may be applied to the MEP, and demonstrates ways in which DEA may be employed to drive continuous improvement efforts. Chapter 3 describes the data set evaluated with DEA. Special attention is placed on the variables analyzed with DEA and how these variables are used to specify models for the data set. Chapter 4 contains the results of the analysis. Detailed results are presented in several different ways in order to generate a deeper understanding of how DEA may be used to drive performance improvement within a individual MEC and for the overall MEP Program. Chapter 5 concludes the report with a summary, conclusions, and suggestions for further research. The basic concepts behind DEA described in Chapter 2 are covered in greater detail in Appendix A and Appendix B. Appendix A presents a graphical approach to performance assessment. Appendix B includes a mathematical formulation of the DEA model structure used throughout this report.

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[3] Norman, Michael, and Stoker, Barry. 1991. *Data Envelopment Analysis: The Assessment of Performance*. New York: John Wiley and Sons.

[4] Boussofiane, A., Dyson, R.G. and Thanassoulis, E. 1991. "Applied Data Envelopment Analysis," *European Journal of Operational Research*, **Vol. 52**, pp. 1-15.

2. Data Envelopment Analysis (DEA): A Summary of Key Concepts

DEA is a mathematical technique that provides an objective assessment of the operating efficiency of each of a number of similar organizational units, relative to each other. Operating efficiencies are derived through reference to a small set of units which collectively define a performance frontier. Units on the frontier are said to be efficient in the allocation of their inputs and the production of their outputs while units not on the frontier are inefficient. It is important to note that units on the frontier exhibit actual achieved performance rather than theoretically optimal performance. Consequently, units on the frontier reflect actual patterns of resource allocation and production rather than theoretically optimal patterns.

Apart from the measure of relative efficiency of each unit, DEA also yields other information which proves useful in gaining a better insight into the performance of each unit and in guiding units to improve their performance. Specifically, DEA identifies efficient peer units for every inefficient unit. These efficient units can prove useful for identifying efficient operating practices which can be disseminated to all units so that they may improve their performance.

Furthermore, DEA permits differing combinations of input and output variables to be analyzed and evaluated. Each combination of variables is a specific model. Cross-model comparisons can then be used to evaluate the implications of adding a new variable or disaggregating an existing one. Cross-model comparisons serve to highlight exemplary practices for each efficient peer unit, producing "paths to improved performance" for less efficient units.

2.1. DEA and the Manufacturing Extension Partnership (MEP) Program

There are a number of reasons why DEA is ideally suited for use by the MEP Program. First, MEP operates a national network of Manufacturing Extension Centers (MECs). Each MEC employs similar types of resources as inputs and provides similar types of services as outputs. Thus the "similar organizational units" referred to above are MECs. Second, DEA enables MEP to take a long-term view of performance assessment rather than a single snapshot of program performance. For example, a particular model, or set of models, can be evaluated with successive data sets to measure the effects of adding "new" MECs and/or the effects of inter-temporal differences in the values of key variables on a particular MEC's performance. Third, MEP has established a management information reporting system which allows a tight coupling between information collected for programmatic reasons and information used for performance assessment via DEA. Finally, DEA is a tool not only for performance assessment but for continuous improvement as well. Thus DEA may be used both for improving the performance of individual MECs and of the overall MEP Program.

To better understand how these pieces fit together, it is instructive to learn more about the MEP Program. The next three subsections provide background information on the MEP Program with particular emphasis on the role of DEA as a performance assessment and continuous improvement tool.

2.1.1. Brief Description of the MEP Program

The NIST/MEP Program is a national network of services to assist smaller manufacturers in becoming globally competitive. MEP combines federal support with state and local organizations to deliver services which address the critical and often unique needs of smaller manufacturers. In 1988, Congress directed NIST to begin helping the nation's smaller manufacturers adopt and apply performance-improving technologies as needed to meet intensifying domestic and global competition in manufacturing. NIST was selected for this role because of its expertise in manufacturing engineering and its long-standing tradition of productive partnerships forged with public and private organizations at the national, state, and local levels. To carry out this role, the MEP conducts a variety of regional, national, and program development activities. Regionally, MEP works with the states or local organizations to establish Manufacturing Extension Centers (MECs) or expand existing services that assist smaller manufacturers.

MECs are designed to help link sources of improved manufacturing technology and the small and mid-sized companies that need it. MEC staff work with individual companies or with groups of companies organized around common needs, industries, or technologies. While each MEC tailors its services to meet the needs dictated by its location and manufacturing client base, some common services are offered by most MECs. Broadly, these include helping manufacturers assess their current technology and business needs, define avenues of change, and implement improvements.

MEP's activities also include helping foster a more unified network by working with MECs to identify and coordinate the services, technology, and information needed at the national scale. MEP is developing a uniform system to help MECs evaluate and continuously improve the success of services they deliver.

2.1.2. Performance Assessment

DEA provides a method which MEP and its network of MECs can use jointly to make sense of the multi-dimensional nature of MEC performance data. DEA can augment, complement, and in important ways improve upon an MEC assessment that uses individual "performance ratios," such as the number of client manufacturing establishments (CMEs) served per full-time equivalent employee (FTE). Performance assessment via DEA can be conducted in a way which takes into account the influence of special circumstances, such as the number of CMEs in the target population, which may affect performance but are beyond the control of individual MECs. Consequently, DEA allows MECs to compare their own performance with that of their peers, while taking

diversity of MEC *outputs, inputs, and special circumstances* into account. While DEA is only one of several MEP approaches to performance assessment, it is a particularly flexible one.

MECs employ a variety of resources in order to achieve multiple desired outcomes in client firms and in their regional economies. As seen in Figure 2.1, MEC resources (inputs) and MEC outcomes (outputs) are *both* multi-dimensional. Figure 2.1 shows two broad categories of inputs--staff and financial resources. The MEC must deploy its staff and financial resources on a number of "fronts" to achieve its objectives (e.g., desired outcomes). Three types of outputs are shown in the figure to capture the multi-dimensional nature of a typical MEC's set of desired outcomes. Although Figure 2.1 is a simplification of how an MEC operates, it provides the basic elements for a meaningful evaluation of MEC performance. Consequently, Figure 2.1 helps us to understand why any attempt to assess MEC performance, to identify peak performers, to highlight approaches which are achieving the greatest success, and to identify improvement opportunities for each MEC *must* take account of the multi-dimensional nature of the MEC's resources and outcomes.

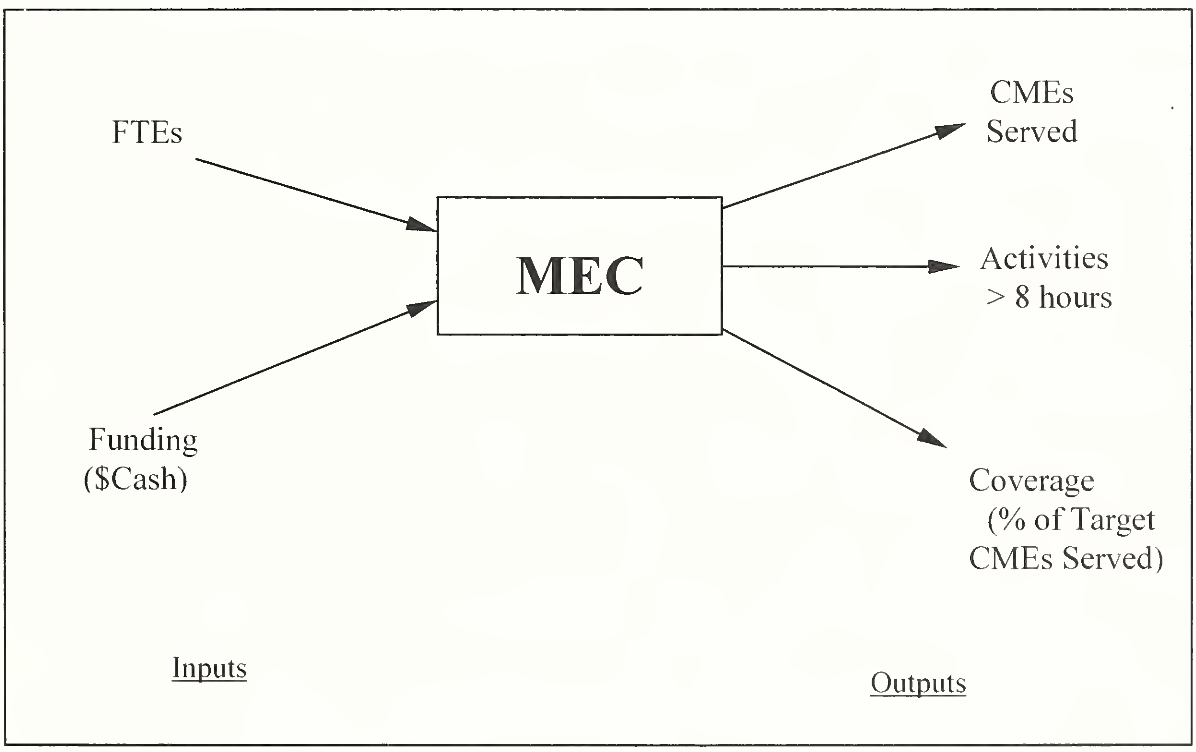

Figure 2. 1 MEC Operations are Multi-Dimensional

The simplest approach to evaluating multi-dimensional performance is to calculate a set of performance ratios containing a ratio for every possible pair of an output and an input (e.g., CMEs served per FTE, activities > 8 hours per FTE, etc.). DEA provides an

integrated method for performance assessment which fulfills the need to address multiple inputs and outputs simultaneously. Thus, DEA produces a *single* measure of performance by taking into account all of the multiple outputs and inputs. In contrast, the approach of performance ratios would lead to a bewildering set of independent and incommensurate performance ratios.

MECs operate under a wide variety of circumstances. Some MECs have been in existence for many years, while others are newly established. Some are located in large and dense urban areas, while others are situated in more sprawling, less populated areas. The regional economies served by the MECs differ in ways which may affect measures of MEC performance. For example, there may be significant variation in average manufacturing firm size, dominant manufacturing industry types, costs faced by regional manufacturers, and trends in the overall economy. Any attempt to comprehensively assess MEC performance must be able to take into account the possible influence of all these factors. DEA fully meets this challenging requirement.

2.1.3. Continuous Improvement

DEA provides a framework for implementing continuous improvement processes both for individual MECs and for the overall MEP Program. Two key concepts are employed to promote individual MEC performance: (1) the performance frontier, a line representing the maximum attained level of MEC performance; and (2) reference centers, those MECs which are on the performance frontier and are most similar to each non-frontier MEC. Both concepts are illustrated graphically in Figure 2.2. Figure 2.2 represents the simplest case involving two outputs and a single input. DEA produces a performance frontier established by a small but well-defined set of MECs. These frontier MECs demonstrate actual *achieved* peak levels of performance. Figure 2.2 contains two such MECs--Frontier Center 1 and Frontier Center 2. The frontier MECs provide the basis for measuring the performance of "less efficient" non-frontier MECs. One non-frontier MEC, Non-Frontier Center ***k***, is shown in Figure 2.2. The frontier MECs also serve as "reference centers" for the non-frontier MECs. In the case illustrated by Figure 2.2, Frontier Centers 1 and 2 are the reference centers for Non-Frontier Center ***k***.

As frontier and non-frontier MECs engage in benchmarking each others' performance metrics, improvements or new approaches to service delivery will be employed. As different approaches are tried and refined, some non-frontier MECs will improve their performance faster than those currently on the frontier. This will likely result in changes in the set of MECs currently on the frontier. Thus, the reference center concept should improve not only individual non-frontier MEC performance (i.e., to get to the frontier) but drive improvement for frontier MECs as well (i.e., to stay on the frontier).

A framework, based on a time series of DEA analyses, can be established to measure performance progress for the overall MEP Program. For example, collection of results may be established through a series of applications of a specific performance assessment model. Since each performance assessment model consists of a fixed set of variables, it

provides the basis for an index measure--a single summary measure--for each MEC. An index measure enables us to track each MEC's efficiency changes over time (e.g., efficiency changes resulting from inter-temporal changes in the quantities of inputs and outputs). For example, are certain MECs consistently on the frontier and how has the position of a non-frontier MEC changed relative to the frontier? Consequently, a time series of DEA analyses may be used to establish a set of "rolling benchmarks" for the MEP Program. These rolling benchmarks will enable MEP headquarters to strengthen its continuous improvement efforts by focusing on pushing the entire performance frontier outwards.

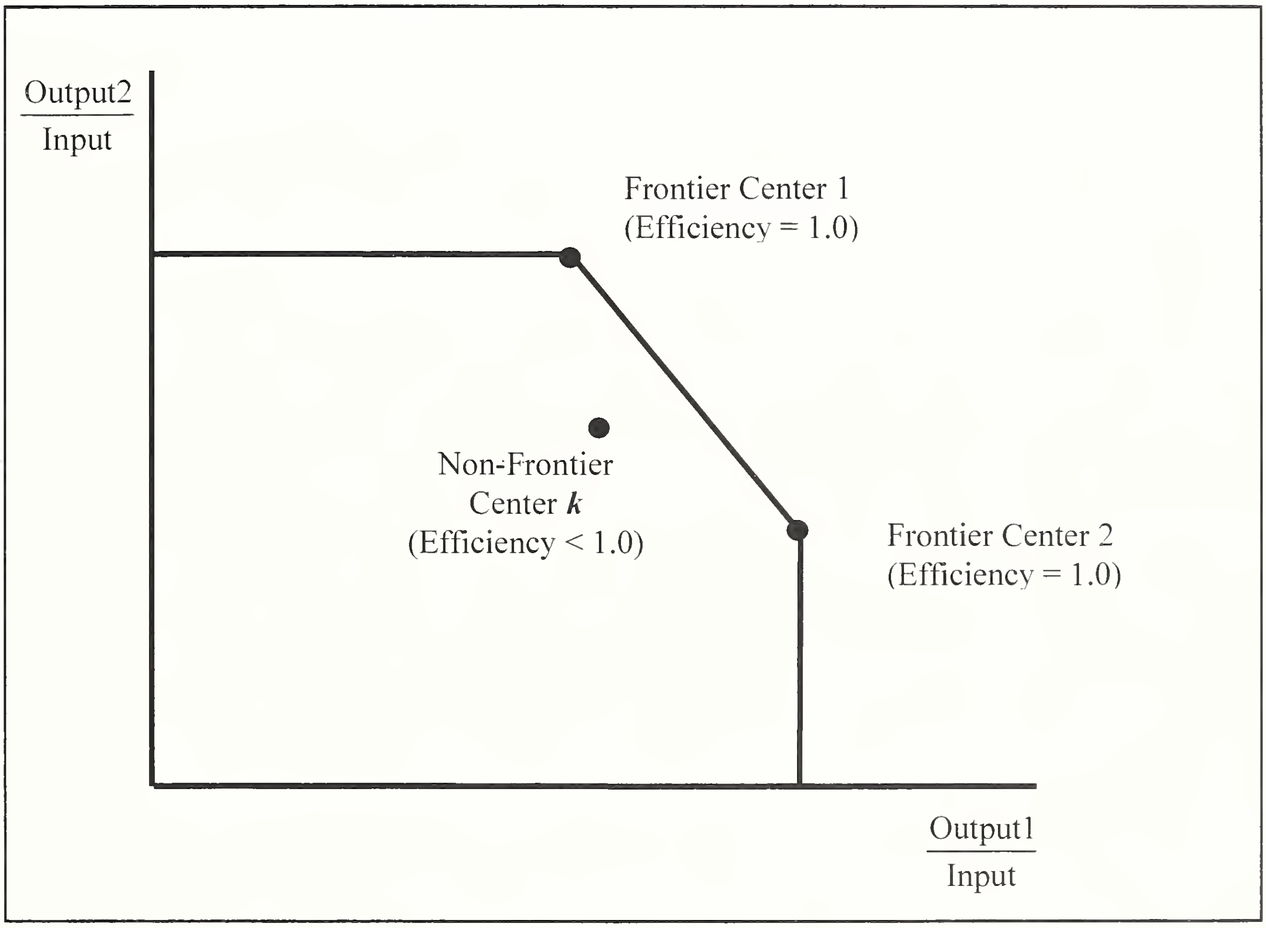

Figure 2. 2 MECs and the Performance Frontier

Figure 2.3 illustrates a movement of the entire performance frontier from the initial time period--the Old Frontier--to the new time period--the New Frontier. The figure traces efficiency changes for three MECs as dotted lines. Note that Non-Frontier Center *k* has improved its performance at a faster rate than the two original frontier MECs.

Changes in the values of the index measures for those MECs on the new frontier, provide a straight-forward way of measuring if the frontier is being pushed outward, or if not,

where it is lagging. In the case illustrated by Figure 2.3, the entire performance frontier has been pushed outward. This indicates an improvement in the national MEP Program.

2.2. The Performance Frontier

DEA is used to assess the performance of a number of comparable entities which consume one or more inputs in the process of producing one or more outputs. DEA refers to these comparable entities as "decision-making units," or DMUs. The concept of a decision making unit is generic. Consequently, we use the specific term MEC to designate the decision making unit (i.e., DMU) of interest.

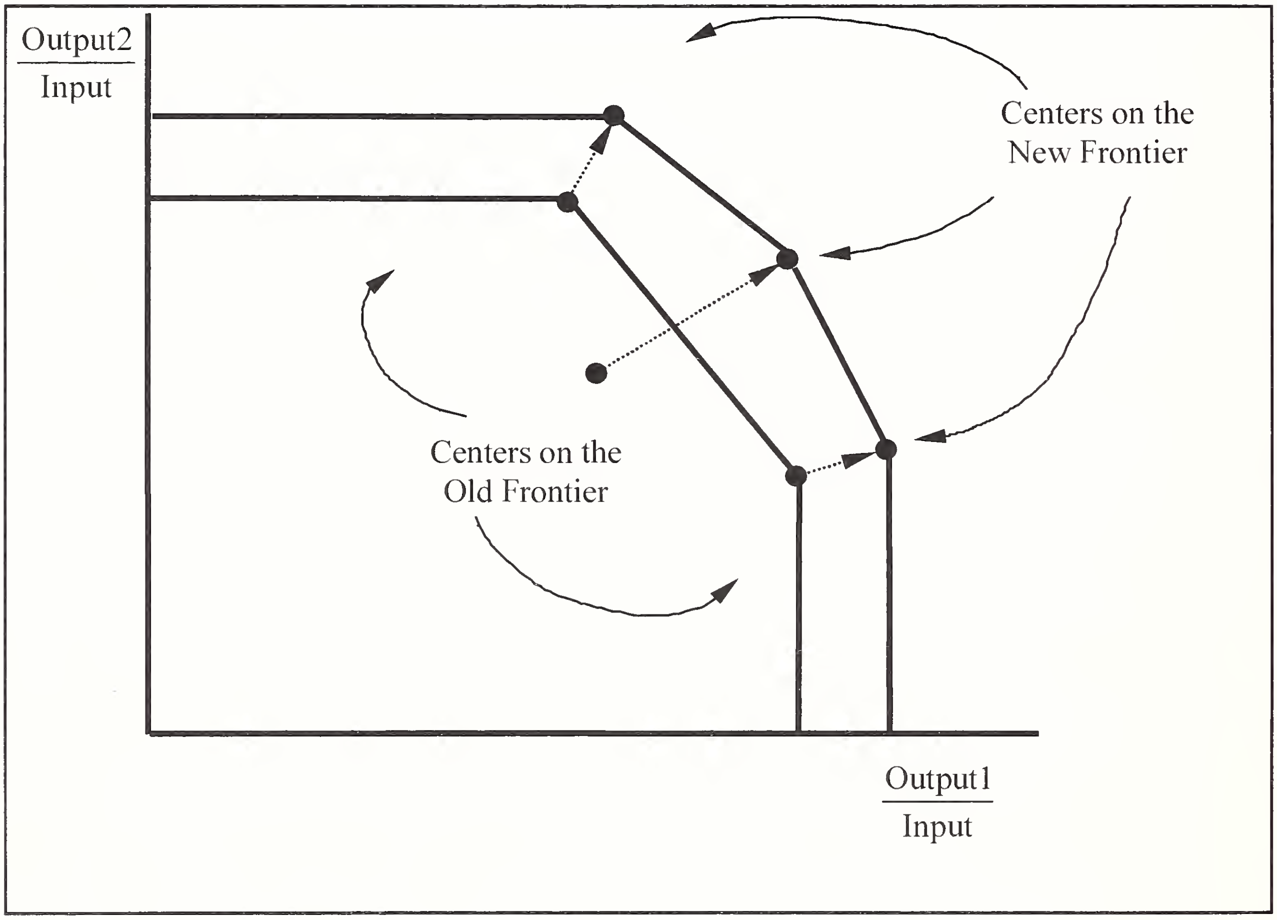

Figure 2. 3 Pushing the Performance Frontier Outwards

DEA provides answers to two types of questions which arise when assessing the performance of MECs: (1) how well is each MEC doing; and (2) how much better could each MEC do. In developing answers to both questions, the benchmark against which MEC performance is assessed by DEA is *demonstrated peak* levels of performance. In DEA terminology, the locus of peak performance possibilities is represented by the performance frontier (e.g., see Figures 2.2 and 2.3). The shape and location of the DEA

performance frontier reflects an important assumption. Namely, *all linear combinations* of actual MEC performance (i.e., frontier MECs) are assumed to be *feasible*.

2.3. Calculating Efficiencies

The shape and location of the frontier also allows us to quantify the degree of under-performance (i.e., room for improvement) for each MEC which is not 100% efficient (i.e., on the frontier). The efficiency of each MEC is calculated as the radial distance (from the origin) to its plotted performance, divided by the total radial distance to the frontier along the path through its plotted performance. DEA's measure of efficiency is illustrated graphically in Figure 2.4. Reference to the figure demonstrates that the ***k***th MEC is compared with that frontier point which has its same relative proportions of inputs and outputs. Appendix A provides a detailed, step-by-step procedure for calculating the efficiency of a non-frontier MEC. The procedure is graphically oriented and uses data from only three MECs.

DEA also produces a set of "peer units" or "reference centers" associated with each MEC not located on the frontier. An interior (non-frontier) MEC's reference centers are those MECs on the frontier which are most similar to the interior MEC in terms of their relative ratios of inputs and outputs. The frontier point with which each interior MEC is compared is the linear combination of its reference centers that results in its exact same relative ratios of inputs and outputs (see Figure 2.4).

The efficiency of each MEC on the frontier is defined as being equal to 1.0 (i.e., 100%). Additionally, the efficiency of each MEC not on the frontier is calculated as the ratio of two radial distances defined by its plotted performance and that frontier point which has its same relative proportions of inputs and outputs. It can be shown that this approach to calculating efficiencies is equivalent to calculating efficiencies as the ratio of the weighted sum of the MEC's outputs divided by the weighted sum of its inputs. The individual weights for each MEC are chosen to maximize its own calculated efficiency, where each MEC's weights must satisfy two sets of constraints. First, the weights are all constrained to be non-negative. Second, the weights are subject to the restriction that neither its own efficiency nor any other MEC's efficiency using these same weights exceed 1.0. While this model formulation is non-linear, the model formulation may be transformed into a linear programming problem. The resultant linear programming problem is individually solved for each MEC.

Consider the case where there are ***n*** MECs. When solving the linear programming problem for the ***k***th MEC, the input weights are selected so that the weighted sum of the inputs equals 1.0. The output weights are selected to maximize the weighted sum of the outputs, and thus the efficiency of the ***k***th MEC. Thus, weights are selected which show each MEC in the best possible light. Does this mean that all MECs are found to be 100% efficient? No, because the second set of constraints requires that *no other MEC* be found more than 100% efficient using those *same input and output* weights. Note that this linear programming problem is solved for the ***k***th MEC. Thus, ***n*** of these separate linear programming problems must be solved to generate the full set of efficiency scores. The

mathematical derivation of the non-linear model formulation and the specification of the linear programming problem are provided in Appendix B.

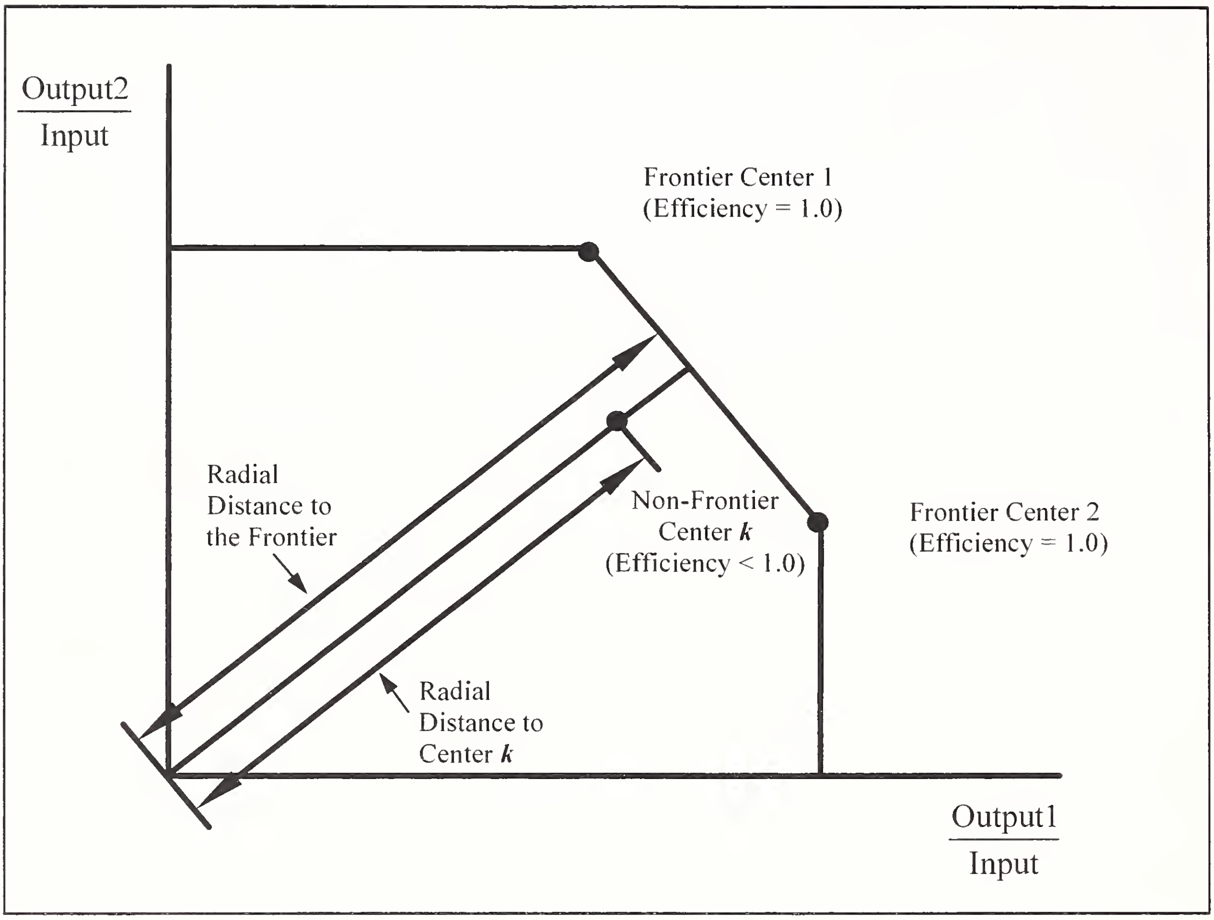

Figure 2. 4 Efficiency and the Performance Frontier

2.4. The Identification of Reference Centers

Note that the MECs which form the *k*th MEC's reference centers are precisely those frontier MECs which are most similar to the *k*th MEC in terms of their relative ratios of inputs and outputs. Linear programming produces an optimum set of input and output weights which maximize the *k*th MEC's efficiency. Both the weights and the calculated efficiency for the *k*th MEC are sensitive to the shape and location of the performance frontier. Because those frontier centers which affect the *k*th MEC's weights and calculated efficiency are its reference centers (see Appendices A and B), a procedure for identifying reference centers is needed.

The identification of reference centers is accomplished through a post-processing operation. This operation examines if one or more of a series of constraints is binding (see Appendix B). If the constraint is binding, then the efficiency of the *k*th MEC would be higher if that constraint were relaxed. Those constraints which are binding for the *k*th MEC correspond to its reference centers.

3. Assessing Manufacturing Extension Center (MEC) Performance: Data, Variables, and Models

This chapter describes the data upon which all DEA analyses were based, the variables which were employed in these analyses, and the specification of each of the performance assessment models evaluated with DEA. All data are derived either from various MEP reports or are from the U.S. Bureau of the Census. The MEP reports are of two types: (1) compiled sets of Monthly Reports; and (2) the Semi-Annual Report. Data from the two MEP reports were used to create the variables used in a series of "standard" analyses. Data from the Census' *County Business Patterns*[5] were used to create the variables used in a series of "exploratory" analyses.

To better understand the relationships between the data, the two types of variables, and the associated performance assessment models, background information on the MEP-related data is first presented. This background information includes an overview of the NIST/MEP reporting system. A brief description of the operating data set follows (see Section 3.1). Each of the two types of variables--"standard" and "exploratory"--are then described (see Section 3.2). The chapter concludes with the specification of each of the performance assessment models evaluated with DEA (see Section 3.3).

The stakeholders in the National MEP system have a diverse set of informational needs. Consequently, the NIST/MEP Management Information Reporting System was designed to collect operational data and qualitative information to meet these diverse informational needs. In addition to these needs, the NIST/MEP reporting system was designed to meet the informational needs related to continuous improvement and program accountability.[6]

Continuous improvement is vital to the long-term success of the MEP Program. The collection and analysis of information can provide insight into the factors leading to effective and efficient provision of services, which lead to continuous improvement. The reporting system standardizes definitions of important concepts which permit the aggregation and statistical analysis of data that can build the knowledge to facilitate improvements. DEA provides a framework for implementing continuous improvement processes both for individual MECs and the overall MEP Program.

NIST/MEP is charged with insuring the efficacy of taxpayer investment in the National system. The reporting system allows NIST/MEP to monitor MEC performance and to ensure that the MEP Program is meeting its goal of "strengthening the global competitiveness of smaller U.S. manufacturers."[7] DEA provides a method which MEP and its network of MECs can use jointly to make sense of the multi-dimensional nature of MEC performance data.

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[5] U.S. Bureau of the Census. 1994. *County Business Patterns*. Washington, DC: U.S. Bureau of the Census.
[6] For a detailed description of the NIST/MEP reporting system see, National Institute of Standards and Technology (NIST). 1996. *NIST/MEP Management Information Reporting Guidelines*. Gaithersburg, MD: National Institute of Standards and Technology.
[7] *Ibid.*,p.1-2.

Two key components of the reporting system are the Monthly Report and the Semi-Annual Report. The Monthly and Semi-Annual Reports provided the basis for all of the metrics used in the "standard" analyses of MEC operating data.

The Monthly Report is a set of two documents that convey information regarding an MEC's finances, activities, and progress towards its plans as outlined in its yearly *Operating Plan*. The first document is a one-page template primarily designed to assist MEP Regional Managers in assessing the MEC's recent expenditures and activity levels by tracking MEC performance over time. The first document also serves to update the central NIST/MEP database. The second document is a brief free-form text document that provides a qualitative perspective on an MEC's progress toward its overall goals as outlined in its *Operating Plan*.

The Semi-Annual Report is made up of several reporting documents, some of which serve to update the central NIST/MEP database, and others of which provide information on various MEC activities. The Semi-Annual Report Data Page is a one-page template that captures information characterizing the cumulative activities of the MEC over time. Specifically, it is designed to capture the total number of activities and events the MEC has completed and the number of client manufacturing establishments (CMEs) with which the MEC has worked. The Semi-Annual Report Data Page is a critical component of the central NIST/MEP data base. Data compiled from the Semi-Annual Report Data Page are at the core of all DEA Analyses.

3.1. Brief Description of the MEC Operating Data Set

The MEC operating data set analyzed with DEA covers the last six months of 1996. This information was drawn from a compiled set of Monthly Reports and the Semi-Annual Report of the last six months of 1996. The MEC operating data set used in this report also incorporated supplementary information from the Census' *County Business Patterns*. The "original" MEC operating data set, supplemented with information from the *County Business Patterns*, contained approximately 110 variables on *each MEC*. The variables in the operating data set provided:

- information needed to identify each MEC (i.e., tags),
- values of inputs (e.g., dollar-denominated, financial-type figures, number of monthly reports submitted, staff counts, etc.), and
- the value of outputs (e.g., activities over 8 hours in duration completed during the reporting period, number of client manufacturing establishments (CMEs) served, percent of CMEs in the target population served, indexes to deflate expenses, etc.).

The MEC operating data are drawn from a compiled set of Monthly Reports and the Semi-Annual Report for the period July 1, 1996 through December 31, 1996. Because

target population data were based on information from the 1994 *County Business Patterns*,[8] it was necessary to exclude from the analysis eight MECs which did not have estimated values for their target population. Furthermore, two MECs were combined into a composite MEC because only state-wide information on target population was available for their state. The resultant data set contains 51 MECs.

In addition to operating data from the Monthly and Semi-Annual Reports, the data set contains information compiled from the *County Business Patterns* on the costs of engineering and management consulting services. These data were used to construct a "consultant cost index" and a series of weighted cost metrics. These "exploratory" metrics are used to identify MECs operating in high cost areas which use their financial resources very efficiently.

3.2. Selection of Variables for Analysis

The key variables being analyzed via DEA are summarized in Tables 3.1 and 3.2. The tables provide the variable name, its definition, and its type. Wherever possible, the same variable name as in the "original" MEC operating data set is used. Those variables which are new (i.e., were derived by Calculation from the original MEC operating data set) have a "C_" as part of their name and the designation as "Calculated" under the Type column heading. Variables are classified into five types: (1) tag (i.e., identifiers); (2) original input; (3) original output; (4) calculated input; and (5) calculated output.

The inputs (i.e., original and calculated) listed in Table 3.1 are classified into three basic types: (1) the number of full-time equivalents--FTEs--(i.e., staff metrics), (2) cash expenses (i.e., financial metrics), and (3) the number of CMEs in the target population. It is important to note that each of the input totals--FTEMOAVE (total FTEs, all personnel) and KC_TOTAL ("revised" total expenses, cash $K)--can be decomposed into two components. The components of FTEMOAVE are: ADMOAVE (FTEs, administrative personnel) and ENGMOAVE (FTEs, field agents plus technical specialists). The components of KC_TOTAL are: KSTOTPER (personnel expenses, cash, $K) and KC_OPS_C ("revised" operations expenses, cash, $K).[9] This approach enables us to decompose the effects of each input (i.e., staff and financial) into its component effects.

Table 3.1 contains five outputs (i.e., original and calculated). One of these outputs, CMEPERID (CMEs served during the reporting period), can be decomposed into two components: CMEFIRST (CMEs served for the first time) and C_CME_RP (CMEs which are repeat business). Another key output, ACT_8, records the number of activities completed greater than 8 hours in duration. This output provides a measure of substantial

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[8] Data on the number of CMEs in the target population were derived from the latest available (1994) *County Business Patterns*. This approach was chosen because it resulted in a single, consistent definition of the target population across all MECs.

[9] The values of total expenses and operations expenses have been "revised" by subtracting out the value of operations expenses for third party providers, THIRDP$. This adjustment was dictated by data anomalies associated with the input variable THIRDP$.

interaction between the MEC and its client base. Another output, C_PCTCME, provides a measure of market penetration (i.e., what percentage of the target population of CMEs was served this period). Thus, the key outputs analyzed cover: (1) the number of CMEs served, including the breakout between new and repeat business, (2) activities which represent substantial interactions, and (3) market penetration.

Table 3.2 records the seven variables used in a series of "exploratory" analyses. The first four variables are used to develop a consultant cost index. The consultant cost index is used to deflate expenses (i.e., KC_TOTAL, KSTOTPER, and KC_OPS_C), adjusting each MEC's expenses for systematic differences in costs among MECs. This "leveling of the playing field" allows MECs which operate in a high-cost area but make efficient use of their financial resources to be identified. The components of the consultant cost index are NDX_TOT, NDX_PER, and NDX_OPS, respectively. Table 3.2 records the seven variables used in a series of "exploratory" analyses.

3.3. Selection of Models for Analysis

A series of performance assessment models was constructed and evaluated with DEA. Each model was a unique combination of inputs and outputs. In all, 48 models were evaluated with DEA.

Tables 3.3 through 3.5 list the models analyzed with DEA. The models specified in Tables 3.3 through 3.5 make use of the same basic elements shown in Figure 2.1. Each set of models is built around one of the key inputs--either staff metrics (FTEs) or financial metrics (cash expenses)--shown in Figure 2.1.

Models for which both the outputs and the inputs are "standard" (i.e., the values for all metrics are based on the variables listed in Table 3.1) are referred to as a "standard" model type. The models listed in Table 3.3 are the "standard" models for staff input metrics. The models listed in Table 3.4 are the "standard" models for financial (cash) input metrics.

Models for which the values of the input metrics are based on the variables listed in Table 3.2 are referred to as an "exploratory" model type. These models are listed in Table 3.5.

Tables 3.3 and 3.4 specify the "standard" models analyzed with DEA. Each table has 16 models. The name of each of the 16 models is given under the column heading, Model. The name of each variable which is an output is listed under the appropriate column heading (i.e., Output No. 1 through Output No. 4). The name of each variable which is an input is listed under the appropriate column heading (i.e., Input No. 1 and Input No. 2). The structure of each table is designed to reveal the differential effect of adding or disaggregating an output and/or disaggregating the input. Note that the outputs are the same and are grouped in the same manner in both tables, so that the effect of each input metric (staff vs. financial) can be directly observed for each model. The inputs are based on either staff metrics (Table 3.3) or financial metrics (Table 3.4).

Table 3. 1 List of Variables for "Standard" Analyses with DEA

Variable Name	Definition	Type
CODE	Center Code	Tag
STOTPER$	Personnel Expenses, Cash	Original Input
THIRDP$	Operations Expenses, Third Party Service Providers, Cash	Original Input
STOTOPS$	Operations Expenses, Subtotal, Cash	Original Input
C_OPS_C	"Revised" Operations Expenses, Cash (Operations Expenses (STOTOPS$) Less Third Party Expenses (THIRDP$))	Calculated Input
C_TOTAL	" Revised" Total Expenses, Cash (Personnel Expenses (STOTPER$) Plus "Revised" Operations Expenses (C_OPS_C)	Calculated Input
KSTOTPER	Personnel Expenses, Cash, $K	Calculated Input
KC_OPS_C	"Revised" Operations Expenses, Cash, $K	Calculated Input
KC_TOTAL	"Revised" Total Expenses, Cash, $K	Calculated Input
ADMOAVE	FTEs, Administrative Personnel	Original Input
ENGMOAVE	FTEs, Field Agents Plus Technical Specialists	Original Input
FTEMOAVE	Total FTEs, All Personnel	Original Input
CMETARGT	CMEs in Target Population, Based on Data Derived from the *County Business Patterns*	Calculated Input
ACT_8	Activities > 8 Hours	Original Output
CMEPERID	CMEs Served During Reporting Period	Original Output
CMEFIRST	CMEs Served for the First Time	Original Output
C_CME_RP	CMEs Served which are Repeat Business (CMEPERID Less CMEFIRST)	Calculated Output
C_PCTCME	Percent of CMEs in Target Population Served (((CMEPERID)/(CMETARGT))*100)	Calculated Output

Table 3. 2   List of Special Variables for "Exploratory" Analyses with DEA

Variable Name	Definition	Type
ENG_SAL	Average Salary for Engineering Consulting Services (SIC Code 8711), Based on Data from County Business Patterns	Calculated Input
MAN_SAL	Average Salary for Management Consulting Services (SIC Code 8742), Based on Data from County Business Patterns	Calculated Input
WGT_CONS	Weighted Average Salary for Consulting Services for this MEC, Based on Proportion of Total FTEs Engaged in Engineering or Management Services Times the Respective Average Salary	Calculated Input
CONS_NDX	Index Used to Deflate Expenses, Weighted Average Salary for Consulting Services for this MEC (WGT_CONS) Divided by the Average Salary for Consulting Services Across all MECs	Calculated Input
NDX_PER	Personnel Expenses, Cash, $K, Indexed for Systematic Cost Differences (KSTOTPER Divided by CONS_NDX)	Calculated Input
NDX_OPS	"Revised" Operations Expenses, Cash, $K, Indexed for Systematic Cost Differences (KC_OPS_C Divided by CONS_NDX)	Calculated Input
NDX_TOT	"Revised" Total Expenses, Cash $K, Indexed for Systematic Cost Differences (KC_TOTAL Divided by CONS_NDX)	Calculated Input

Table 3.3 records the 16 "standard" staff models analyzed with DEA. The first set of four models (Staff Model 1 through Staff Model 4) represents all possible combinations of two outputs or a single output (CMEPERID) disaggregated into its two component parts. These models are grouped so as to provide the basis for measuring the effects of either adding another output or disaggregating FTEMOAVE into its two component parts, ADMOAVE (the number of administrative staff) and ENGMOAVE (the number of field staff). The second set of four models (Staff Model 5 through Staff Model 8) maintains the same output pattern as the first set of four models but disaggregates FTEMOAVE into its two component parts. The next set of three models (Staff Model 9 through Staff Model 11) adds a third output but with a single input, FTEMOAVE. These models enable us to measure the effect of adding a third variable or of disaggregating the number of CMEs served into its two component parts. The next set of three models (Staff Model 12 through Staff Model 14) measures the effect of disaggregating FTEMOAVE into its two component parts, while maintaining three outputs. The last set of two models measures the effect of adding a fourth output with a single input (Staff Model 15) and of disaggregating FTETMOAVE into its two component parts (Staff Model 16).

Table 3.4 records the 16 "standard" financial models analyzed with DEA. The first set of four models (Financial Model 1 through Financial Model 4) represents all possible combinations of two outputs or a single output (CMEPERID) disaggregated into its two component parts. These models are grouped so as to provide the basis for measuring the effects of either adding another output or disaggregating KC_TOTAL into its two component parts, KSTOTPER (personnel expenses) and KC_OPS_C (operations expenses less third-party expenses). The second set of four models (Financial Model 5 through Financial Model 8) maintains the same output pattern as the first set of four models but disaggregates KC_TOTAL into its two component parts. The next set of three models (Financial Model 9 through Financial Model 11) adds a third output but with a single input, KC_TOTAL. These models enable us to measure the effect of adding a third variable or of disaggregating the number of CMEs served into its two component parts. The next set of three models (Financial Model 12 through Financial Model 14) measures the effect of disaggregating KC_TOTAL into its two component parts, while maintaining three outputs. The last set of two models measures the effect of adding a fourth output with a single input (Financial Model 15) and of disaggregating KC_TOTAL into its two component parts (Financial Model 16).

Table 3.5 records the 16 "indexed" financial models. The four "standard" output metrics are analyzed via an indexed set of financial inputs. Except for indexing, the models shown in Table 3.5 follow the same structure as those shown in Table 3.4. Specifically, personnel expenses, "revised" operations expenses, and "revised" total expenses are all indexed for systematic cost differences. These "indexed" financial models are designed to adjust each MEC's expenses for systematic differences in costs among MECs. This approach allows MECs which operate in a high-cost area but make efficient use of their financial resources to be identified.

Table 3. 3 Models Analyzed with DEA: Based on "Standard" Output Metrics and Staff Input Metrics

Model	Output No. 1	Output No. 2	Output No. 3	Output No. 4	Input No. 1	Input No. 2
Staff Model 1	ACT_8	CMEPERID	---	---	FTEMOAVE	---
Staff Model 2	ACT_8	C_PCTCME	---	---	FTEMOAVE	---
Staff Model 3	CMEPERID	C_PCTCME	---	---	FTEMOAVE	---
Staff Model 4	CMEFIRST	C_CME_RP	---	---	FTEMOAVE	---
Staff Model 5	ACT_8	CMEPERID	---	---	ADMOAVE	ENGMOAVE
Staff Model 6	ACT_8	C_PCTCME	---	---	ADMOAVE	ENGMOAVE
Staff Model 7	CMEPERID	C_PCTCME	---	---	ADMOAVE	ENGMOAVE
Staff Model 8	CMEFIRST	C_CME_RP	---	---	ADMOAVE	ENGMOAVE
Staff Model 9	ACT_8	C_PCTCME	CMEPERID	---	FTEMOAVE	---
Staff Model 10	ACT_8	CMEFIRST	C_CME_RP	---	FTEMOAVE	---
Staff Model 11	C_PCTCME	CMEFIRST	C_CME_RP	---	FTEMOAVE	---
Staff Model 12	ACT_8	C_PCTCME	CMEPERID	---	ADMOAVE	ENGMOAVE
Staff Model 13	ACT_8	CMEFIRST	C_CME_RP	---	ADMOAVE	ENGMOAVE
Staff Model 14	C_PCTCME	CMEFIRST	C_CME_RP	---	ADMOAVE	ENGMOAVE
Staff Model 15	ACT_8	C_PCTCME	CMEFIRST	C_CME_RP	FTEMOAVE	---
Staff Model 16	ACT_8	C_PCTCME	CMEFIRST	C_CME_RP	ADMOAVE	ENGMOAVE

Note: If the third or fourth output or second input is not analyzed in a particular model, the character string --- is entered under that column heading.

Table 3. 4 Models Analyzed with DEA: Based on "Standard" Output Metrics and Financial (Cash) Input Metrics

Model	Output No. 1	Output No. 2	Output No. 3	Output No. 4	Input No. 1	Input No. 2
Financial Model 1	ACT_8	CMEPERID	---	---	KC_TOTAL	---
Financial Model 2	ACT_8	C_PCTCME	---	---	KC_TOTAL	---
Financial Model 3	CMEPERID	C_PCTCME	---	---	KC_TOTAL	---
Financial Model 4	CMEFIRST	C_CME_RP	---	---	KC_TOTAL	---
Financial Model 5	ACT_8	CMEPERID	---	---	KSTOTPER	KC_OPS_C
Financial Model 6	ACT_8	C_PCTCME	---	---	KSTOTPER	KC_OPS_C
Financial Model 7	CMEPERID	C_PCTCME	---	---	KSTOTPER	KC_OPS_C
Financial Model 8	CMEFIRST	C_CME_RP	---	---	KSTOTPER	KC_OPS_C
Financial Model 9	ACT_8	C_PCTCME	CMEPERID	---	KC_TOTAL	---
Financial Model 10	ACT_8	CMEFIRST	C_CME_RP	---	KC_TOTAL	---
Financial Model 11	C_PCTCME	CMEFIRST	C_CME_RP	---	KC_TOTAL	---
Financial Model 12	ACT_8	C_PCTCME	CMEPERID	---	KSTOTPER	KC_OPS_C
Financial Model 13	ACT_8	CMEFIRST	C_CME_RP	---	KSTOTPER	KC_OPS_C
Financial Model 14	C_PCTCME	CMEFIRST	C_CME_RP	---	KSTOTPER	KC_OPS_C
Financial Model 15	ACT_8	C_PCTCME	CMEFIRST	C_CME_RP	KC_TOTAL	---
Financial Model 16	ACT_8	C_PCTCME	CMEFIRST	C_CME_RP	KSTOTPER	KC_OPS_C

Note: If the third or fourth output or second input is not analyzed in a particular model, the character string --- is entered under that column heading.

Table 3. 5 Models Analyzed with DEA: Based on "Standard" Output Metrics and "Indexed" Financial (Cash) Input Metrics

Model	Output No. 1	Output No. 2	Output No. 3	Output No. 4	Input No. 1	Input No. 2
"Indexed" Financial 1	ACT_8	CMEPERID	---	---	NDX_TOT	---
"Indexed" Financial 2	ACT_8	C_PCTCME	---	---	NDX_TOT	---
"Indexed" Financial 3	CMEPERID	C_PCTCME	---	---	NDX_TOT	---
"Indexed" Financial 4	CMEFIRST	C_CME_RP	---	---	NDX_TOT	---
"Indexed" Financial 5	ACT_8	CMEPERID	---	---	NDX_PER	NDX_OPS
"Indexed" Financial 6	ACT_8	C_PCTCME	---	---	NDX_PER	NDX_OPS
"Indexed" Financial 7	CMEPERID	C_PCTCME	---	---	NDX_PER	NDX_OPS
"Indexed" Financial 8	CMEFIRST	C_CME_RP	---	---	NDX_PER	NDX_OPS
"Indexed" Financial 9	ACT_8	C_PCTCME	CMEPERID	---	NDX_TOT	---
"Indexed" Financial 10	ACT_8	CMEFIRST	C_CME_RP	---	NDX_TOT	---
"Indexed" Financial 11	C_PCTCME	CMEFIRST	C_CME_RP	---	NDX_TOT	---
"Indexed" Financial 12	ACT_8	C_PCTCME	CMEPERID	---	NDX_PER	NDX_OPS
"Indexed" Financial 13	ACT_8	CMEFIRST	C_CME_RP	---	NDX_PER	NDX_OPS
"Indexed" Financial 14	C_PCTCME	CMEFIRST	C_CME_RP	---	NDX_PER	NDX_OPS
"Indexed" Financial 15	ACT_8	C_PCTCME	CMEFIRST	C_CME_RP	NDX_TOT	---
"Indexed" Financial 16	ACT_8	C_PCTCME	CMEFIRST	C_CME_RP	NDX_PER	NDX_OPS

Note: If the third or fourth output or second input is not analyzed in a particular model, the character string --- is entered under that column heading.

4. Assessing MEC Performance: Results

Tables 4.1 through 4.6 summarize the results from applying DEA to each of the models listed in Tables 3.3 through 3.5. The first set of three tables, Tables 4.1 through 4.3, covers the disaggregated-output, two-input models (e.g., Table 4.1 covers Staff Model 16 from Table 3.3, Table 4.2 covers Financial Model 16 from Table 3.4, and Table 4.3 cover "Indexed" Financial Model 16 from Table 3.5).

The second set of three tables provides results for each set of models specified in Tables 3.3 through 3.5 (e.g., Table 4.4 covers the 16 staff models specified in Table 3.3, Table 4.5 covers the 16 financial models specified in Table 3.4, and Table 4.6 covers the 16 "indexed" financial models specified in Table 3.5).

4.1. Efficiency Ranges and Reference Centers for Each MEC

Tables 4.1 through 4.3 list the calculated efficiency ranges and reference centers for each of the most detailed models listed in Tables 3.3 through 3.5. All three tables have the same basic format. This was done to simplify comparisons across model types. In the first column of Tables 4.1 through 4.3, the name of each MEC is listed beneath the column heading Center Name. The data set analyzed via DEA contained information from 51 MECs. In order to simplify the reporting of results, all MECs were assigned a sequence number. The sequence numbers range from MEC01 to MEC 51. The MECs are listed sequentially. The second column provides the calculated efficiency range for each MEC. Those MECs which define the performance frontier are shown in **bold face**. In order to assign each MEC to an efficiency range, all MECs were first rank-ordered according to their calculated efficiency. Based on this rank ordering, three statisically-based ranges are used to characterize MEC performance. These ranges are: (1) the top 25 percent, designated as the upper-quartile range; (2) the bottom 25 percent, designated as the lower-quartile range; and (3) the middle 50 percent, designated as the inter-quartile range. MECs in the upper-quartile range are further subdivided into frontier and non-frontier MECs. The entries in the second column are as follows: (1) Frontier (i.e., an MEC in the upper-quartile range which is on the frontier); (2) Upper (i.e., an MEC in the upper-quartile range which is NOT on the frontier); (3) Inter (i.e., an MEC which is in the inter-quartile range); and (4) Lower (i.e., an MEC which is in the lower-quartile range). Because there are 51 MECs, both the upper- and lower-quartile ranges are assumed to contain 13 MECs.

The next four columns of Tables 4.1 through 4.3 contain the identities of each MEC's reference centers. Recall that the reference centers are those frontier MECs which are most similar--in terms of their relative shares of inputs and outputs--to the MEC under analysis. It is important to recognize that both the number of frontier MECs and the identities of the reference centers are model dependent. This is because each model represents a unique combination of inputs and outputs. Consequently, some models will have more frontier MECs--due to a specific combination of inputs and outputs--and, thus, have more opportunities for producing reference centers.

Table 4.1 lists the calculated efficiency ranges and reference centers for each of the 51 MECs analyzed via Staff Model 16. The eight MECs which define the performance frontier are shown in **bold face**. The eight MECs are: (1) MEC04; (2) MEC09; (3) MEC18; (4) MEC27; (5) MEC36; (6) MEC39; (7) MEC40; and (8) MEC44. Note that the eight MECs which define the performance frontier are their own reference centers. For non-frontier MECs, the number of reference centers ranges from one to three.

Table 4.2 lists the calculated efficiency ranges and reference centers for each of the 51 MECs analyzed via Financial Model 16. The six MECs which define the performance frontier are shown in **bold face**. The six MECs are: (1) MEC03; (2) MEC04; (3) MEC09; (4) MEC11; (5) MEC27; and (6) MEC37. Note that the six MECs which define the performance frontier are their own reference centers. For non-frontier MECs, the number of reference centers ranges from two to four.

Table 4.3 lists the calculated efficiency ranges and reference centers for each of the 51 MECs analyzed via "Indexed" Financial Model 16. In "Indexed" Financial Model 16, the four "standard" output metrics are analyzed via an indexed set of financial inputs. Specifically, personnel expenses, "revised" operations expenses, and "revised" total expenses are all indexed for systematic cost differences. This approach allows MECs which operate in a high-cost area but make efficient use of their financial resources to be identified. The eight MECs which define the performance frontier are shown in **bold face**. The eight MECs are: (1) MEC03; (2) MEC04; (3) MEC09; (4) MEC11; (5) MEC26; (6) MEC27; (7) MEC37; and (8) MEC39. Note that the eight MECs which define the performance frontier are their own reference centers. For non-frontier MECs, the number of reference centers ranges from two to four.

Comparisons between Table 4.1, 4.2, and 4.3 show that frontier MECs in one model are not necessarily frontier MECs in another model. For example, MEC11 is a frontier MEC for Financial Model 16 but is not a frontier MEC for Staff Model 16. Three MECs—MEC04, MEC09, and MEC27--are on the frontier for **all three** of the models. Because these MECs are efficiently allocating both their staff and their financial resources, they merit a close examination. It is important to note that these three MECs exhibit efficiency through "diversification" (i.e., efficiency in the utilization of both their staff and financial resources). Furthermore, results like these--where a particular MEC is on the frontier for several different models, especially models with different types of inputs--provide a framework for identifying "best practices." Identifying best practices is extremely important for the MEP Program, because best practices are a key component for establishing a meaningful benchmarking process among MECs.

Table 4. 1 MEC Efficiency Ranges and Reference Centers: Based on "Standard" Output Metrics and Staff Input Metrics (Staff Model 16)

Center Name	Quartile	Reference Centers			
		No. 1	No. 2	No. 3	No. 4
MEC01	Inter	MEC04	MEC44		
MEC02	Inter	MEC44	MEC40		
MEC03	Inter	MEC40	MEC36		
MEC04	**Frontier**	**MEC04**			
MEC05	Inter	MEC18	MEC04	MEC40	
MEC06	Lower	MEC44	MEC40	MEC09	
MEC07	Lower	MEC04	MEC40	MEC18	
MEC08	Inter	MEC44	MEC40		
MEC09	**Frontier**	**MEC09**			
MEC10	Lower	MEC40	MEC27		
MEC11	Upper	MEC40	MEC09		
MEC12	Inter	MEC44			
MEC13	Upper	MEC04	MEC44	MEC40	
MEC14	Upper	MEC04	MEC44		
MEC15	Lower	MEC18	MEC40		
MEC16	Inter	MEC40	MEC04	MEC39	
MEC17	Inter	MEC18			
MEC18	**Frontier**	**MEC18**			
MEC19	Inter	MEC40	MEC04	MEC39	
MEC20	Lower	MEC40	MEC09		
MEC21	Inter	MEC44	MEC40		
MEC22	Lower	MEC40	MEC18		
MEC23	Upper	MEC04	MEC44	MEC40	
MEC24	Inter	MEC40	MEC18		
MEC25	Inter	MEC44	MEC40		
MEC26	Upper	MEC04	MEC44	MEC40	
MEC27	**Frontier**	**MEC27**			
MEC28	Inter	MEC44	MEC40		
MEC29	Inter	MEC40			
MEC30	Lower	MEC40	MEC39		
MEC31	Lower	MEC40	MEC27		
MEC32	Inter	MEC44	MEC40		
MEC33	Inter	MEC44	MEC40		
MEC34	Inter	MEC44	MEC09	MEC40	
MEC35	Inter	MEC18	MEC40		
MEC36	**Frontier**	**MEC36**			
MEC37	Lower	MEC18	MEC40		
MEC38	Inter	MEC44	MEC40		
MEC39	**Frontier**	**MEC39**			
MEC40	**Frontier**	**MEC40**			
MEC41	Lower	MEC18	MEC40		
MEC42	Lower	MEC44			
MEC43	Inter	MEC40	MEC04	MEC44	
MEC44	**Frontier**	**MEC44**			
MEC45	Lower	MEC44	MEC40		
MEC46	Lower	MEC40	MEC39		
MEC47	Inter	MEC40	MEC44		
MEC48	Inter	MEC44	MEC40		
MEC49	Inter	MEC44			
MEC50	Inter	MEC40	MEC18		
MEC51	Inter	MEC04	MEC40	MEC39	

Table 4. 2 MEC Efficiency Ranges and Reference Centers: Based on "Standard" Output Metrics and Financial Input Metrics (Financial Model 16)

Center Name	Quartile	Reference Centers			
		No. 1	No. 2	No. 3	No. 4
MEC01	Inter	MEC04	MEC03	MEC11	
MEC02	Inter	MEC11	MEC09		
MEC03	**Frontier**	**MEC03**			
MEC04	**Frontier**	**MEC04**			
MEC05	Inter	MEC04	MEC37	MEC03	
MEC06	Lower	MEC03	MEC11	MEC04	
MEC07	Lower	MEC04	MEC37	MEC11	MEC09
MEC08	Inter	MEC11	MEC03		
MEC09	**Frontier**	**MEC09**			
MEC10	Lower	MEC11	MEC37	MEC09	
MEC11	**Frontier**	**MEC11**			
MEC12	Inter	MEC11	MEC09		
MEC13	Inter	MEC04	MEC11	MEC09	MEC37
MEC14	Inter	MEC04	MEC11	MEC09	
MEC15	Lower	MEC37	MEC03	MEC04	
MEC16	Inter	MEC11	MEC37	MEC09	MEC04
MEC17	Inter	MEC03	MEC37	MEC04	
MEC18	Upper	MEC04	MEC37	MEC09	
MEC19	Upper	MEC11	MEC03	MEC37	MEC04
MEC20	Lower	MEC37	MEC11	MEC03	MEC04
MEC21	Inter	MEC11	MEC03	MEC37	
MEC22	Lower	MEC03	MEC37	MEC11	
MEC23	Upper	MEC04	MEC11	MEC09	
MEC24	Lower	MEC37	MEC04	MEC11	MEC09
MEC25	Upper	MEC11	MEC37	MEC04	MEC09
MEC26	Inter	MEC04	MEC03	MEC11	
MEC27	**Frontier**	**MEC27**			
MEC28	Inter	MEC11	MEC03	MEC04	
MEC29	Inter	MEC11	MEC03	MEC37	
MEC30	Inter	MEC11	MEC37	MEC03	
MEC31	Lower	MEC11	MEC03		
MEC32	Inter	MEC11	MEC04	MEC03	
MEC33	Upper	MEC11	MEC03	MEC37	
MEC34	Inter	MEC11	MEC03	MEC37	
MEC35	Inter	MEC03	MEC37		
MEC36	Inter	MEC37	MEC09		
MEC37	**Frontier**	**MEC37**			
MEC38	Inter	MEC04	MEC37	MEC11	MEC09
MEC39	Upper	MEC27	MEC09	MEC11	
MEC40	Upper	MEC03	MEC11	MEC37	
MEC41	Lower	MEC37	MEC04	MEC03	
MEC42	Lower	MEC03	MEC11		
MEC43	Inter	MEC04	MEC11	MEC09	
MEC44	Inter	MEC11	MEC04	MEC09	MEC37
MEC45	Lower	MEC11	MEC03	MEC37	
MEC46	Lower	MEC11	MEC03	MEC37	
MEC47	Lower	MEC11	MEC04	MEC37	MEC09
MEC48	Inter	MEC11	MEC03	MEC37	
MEC49	Inter	MEC11	MEC09		
MEC50	Inter	MEC37	MEC03	MEC11	MEC04
MEC51	Inter	MEC04	MEC11	MEC09	

Table 4. 3 MEC Efficiency Ranges and Reference Centers: Based on "Standard" Output Metrics and "Indexed" Financial Input Metrics ("Indexed" Financial Model 16)

Center Name	Quartile	Reference Centers			
		No. 1	No. 2	No. 3	No. 4
MEC01	Inter	MEC04	MEC26	MEC03	
MEC02	Inter	MEC11	MEC09		
MEC03	**Frontier**	**MEC03**			
MEC04	**Frontier**	**MEC04**			
MEC05	Inter	MEC04	MEC37	MEC09	
MEC06	Lower	MEC03	MEC11	MEC26	
MEC07	Lower	MEC04	MEC37	MEC11	MEC09
MEC08	Inter	MEC11	MEC03		
MEC09	**Frontier**	**MEC09**			
MEC10	Lower	MEC11	MEC37	MEC27	
MEC11	**Frontier**	**MEC11**			
MEC12	Lower	MEC11	MEC09		
MEC13	Inter	MEC04	MEC11	MEC09	MEC37
MEC14	Inter	MEC04	MEC11	MEC09	
MEC15	Lower	MEC37	MEC03	MEC04	
MEC16	Inter	MEC11	MEC37	MEC09	MEC04
MEC17	Inter	MEC03	MEC37	MEC04	
MEC18	Upper	MEC04	MEC37	MEC09	
MEC19	Inter	MEC11	MEC03	MEC37	MEC04
MEC20	Lower	MEC37	MEC11	MEC03	MEC04
MEC21	Inter	MEC11	MEC03	MEC37	
MEC22	Lower	MEC03	MEC37	MEC11	
MEC23	Upper	MEC04	MEC09	MEC11	
MEC24	Inter	MEC37	MEC04	MEC11	MEC09
MEC25	Inter	MEC11	MEC37	MEC04	MEC09
MEC26	**Frontier**	**MEC26**			
MEC27	**Frontier**	**MEC27**			
MEC28	Inter	MEC11	MEC03	MEC26	
MEC29	Inter	MEC11	MEC03		
MEC30	Inter	MEC11	MEC37	MEC03	
MEC31	Lower	MEC11	MEC03		
MEC32	Inter	MEC11	MEC26	MEC03	
MEC33	Upper	MEC11	MEC03	MEC37	
MEC34	Inter	MEC11	MEC03	MEC37	
MEC35	Inter	MEC03	MEC37		
MEC36	Inter	MEC37	MEC09		
MEC37	**Frontier**	**MEC37**			
MEC38	Inter	MEC04	MEC11	MEC09	MEC37
MEC39	**Frontier**	**MEC39**			
MEC40	Upper	MEC03	MEC11	MEC37	
MEC41	Lower	MEC37	MEC04	MEC09	
MEC42	Lower	MEC03	MEC11		
MEC43	Lower	MEC04	MEC11	MEC09	
MEC44	Inter	MEC11	MEC04	MEC09	MEC37
MEC45	Lower	MEC11	MEC03	MEC37	
MEC46	Lower	MEC11	MEC03	MEC37	
MEC47	Inter	MEC11	MEC37	MEC09	
MEC48	Upper	MEC11	MEC37	MEC03	
MEC49	Inter	MEC11	MEC09		
MEC50	Inter	MEC37	MEC03	MEC11	MEC04
MEC51	Inter	MEC04	MEC11	MEC09	

Four MECs-- MEC03, MEC11, MEC37, and MEC39--are on the frontier for two of the three models. For three of the four MECs just mentioned, the type of model--staff or financial--determines if they are on the frontier. The exception is MEC39. MEC39 is on the frontier for Staff Model 16 and "Indexed" Financial Model 16 but not for Financial Model 16. In this case, indexing brings MEC39 to the frontier. It is important to note that MEC03, MEC11, and MEC37 are on the frontier only for Financial Model 16 and "Indexed" Financial Model 16. These results demonstrate that while MEC03, MEC11, MEC36, and MEC37 are efficient, their efficiency comes at the expense of "specialization." Thus, they represent improvement opportunities for their "associated" non-frontier MECs, while at the same time can improve their performance in another dimension through diversification.

Comparisons between Table 4.1, 4.2, and 4.3 are also helpful in identifying MECs which are consistently doing a "good" job of allocating their staff and financial resources. For example, if an MEC is consistently in the upper-quartile range--either as a frontier or non-frontier center--they may merit a close examination. Five MECs are in the upper-quartile range, but not always as a frontier center, for all three models. These MEC's are: (1) MEC11; (2) MEC18; (3) MEC23; (4) MEC39; and (5) MEC40. Although these MECs do not exhibit consistent, frontier-level performance, they are consistently performing well in comparison to the overall set of MECs.

4.2. Cross-Model Comparisons

The results presented in Section 4.1 raise two sets of questions. First, why are certain MECs on the frontier? Is it due to a particular output or, in the case of CMEPERID, to one of its components? Is it due to the level of the MEC's staff and financial inputs or to one of each input's components? The response to this set of questions occupies much of this section and Section 4.3.

Second, are some MECs fundamentally different? Is some form of stratification within a particular data set necessary? The answer to this set of questions is more complex. It is true that certain "groups" of MECs face different market conditions. Some MECs operate in rural areas, others in urban areas. Some MECs are newly established, others have been in operation for years. Information and analyses presented in Sections 4.2 and 4.3 provide needed insights on the issues just raised but fall short of a complete response to the second set of questions. A partial response is given at the end of Section 4.3 and elaborated upon in Section 5.3.

Our objective in performing cross-model comparisons--a structured, step-by-step analysis of the differential effect of adding and/or disaggregating an output and/or disaggregating the input--is to illustrate DEA's potential for understanding what the data reveal. The cross-model comparisons are illustrated through a series of tables. The salient results from each table are summarized and analyzed in the accompanying text. At the conclusion of this section, two "paths to improved performance" are defined and described in detail for a key set of models.

Tables 4.4 through 4.6 summarize the key results for each set of models. In each table, the model name is listed under the first column heading, Model. The identity of each MEC in the upper-quartile range (i.e., the top 25 percent of those MECs analyzed) and in the lower-quartile range (i.e., the bottom 25 percent of those MECs analyzed) is listed in the table. Due to lack of space, the identity of the MECs in the inter-quartile range (i.e., the middle 50 percent) are not listed in Tables 4.4 through 4.6.

The upper-quartile range is subdivided into the frontier MECs and the non-frontier MECs. Because all frontier MECs have an efficiency of 1.000, they are listed in sequential order for each model. Non-frontier MECs--both those in the upper-quartile range and those in the lower-quartile range--are listed in descending order of efficiency. To determine if a particular MEC is in the upper-quartile range, in the lower-quartile range, or in the inter-quartile range for a given model, first choose the MEC, then review the appropriate table. The complete list of the MECs analyzed are listed in sequential order in the tables in Section 4.1.

Tables 4.4 and 4.5 summarize the key results for each of the 16 staff models (see Table 4.4) and for each of the 16 financial models (see Table 4.5). Table 4.6 summarizes the key results for each of the 16 "indexed" financial models. These results will be examined in detail. This approach is taken as a means of illustrating the step-by-step progression referred to above.

Consider MEC36 and MEC23. Among the 16 staff models shown in Table 4.4, MEC36 was in the lower-quartile range once (for Staff Model 2), was in the upper-quartile range 10 times four times as a frontier center (for Staff Models 8, 13, 14, and 16) and six times as a non-frontier center (for Staff Models 4, 5, 7, 10, 11, and 15), and was in the inter-quartile range five times. In all cases where MEC 36 was on the frontier, both FTEMOAVE and CMEPERID were disaggregated. Four of the six cases where MEC36 was not in the upper-quartile range were associated with the same combination of outputs --ACT_8 and C_PCTCME (see Table 3.3). Among the 16 staff models, MEC23 was in the upper-quartile range 10 times (for Staff Models 2, 3, 6, 7, 9, 11, 12, 14, 15, and 16) and was in the inter-quartile range six times. In all cases where MEC23 was in the upper-quartile range, the same output was present --C_PCTCME. Thus one would expect that MEC23 has achieved good market penetration.

Among the 16 financial models (see Table 4.5), MEC36 was in the lower-quartile range twice (for Financial Models 2 and 6) and in the inter-quartile range 14 times. Both times MEC36 was in the lower-quartile range, it was with the same combination of outputs--ACT_8 and C_PCTCME. Among the 16 financial models, MEC23 was in the upper-quartile range 11 times--each time *not as* a frontier MEC--and was in the inter-quartile range five times.

Among the 16 "indexed" financial models (see Table 4.6), MEC36 was in the lower-quartile twice (for "Indexed" Financial Models 2 and 6) and in the inter-quartile range 14 times. Both times MEC36 was in the lower-quartile range, it was with the same

combination of outputs--ACT_8 and C_PCTCME. Thus indexing for systematic differences in costs faced by MEC36 is not sufficient to overcome MEC36's "relatively" lower levels of performance on ACT_8 and C_PCTCME. Among the 16 financial models, MEC23 was in the upper-quartile range 10 times--each time *not as* a frontier MEC--and was in the inter-quartile range six times.

Comparing Table 4.6 to Table 4.5 reveals two interesting types of movement for MEC23. First, MEC23 has moved out of the upper-quartile range for "Indexed" Financial Model 8. Examining the characteristics of "Indexed" Financial Model 8 reveals that it disaggregates CMEPERID into its two constituent parts (see Table 3.5). These characteristics are also present in Financial Models 4, 10, and 13 (see Table 3.4) and "Indexed" Financial Models 4, 10, and 13 (see Table 3.5) for which MEC23 was in the inter-quartile range. Second, in all other cases, MEC23's relative position within the upper-quartile range has improved. Specifically, for "Indexed" Financial Models 12, 14, and 16 it is the highest ranked non-frontier MEC. Examining the characteristics of "Indexed" Financial Models 12, 14, and 16 reveals that these models all contain the market penetration output metric, C_PCTCME, and the disaggregated financial input metrics, NDX_PER and NDX_OPS.

Recall that our objective in performing cross-model comparisons--a structured, step-by-step analysis of the differential effect of adding and/or disaggregating an output and/or disaggregating the input--is to illustrate DEA's potential for understanding what the data reveal. Table 4.6 provides a framework for conducting another aspect of cross-model comparisons. To illustrate this aspect, consider "Indexed" Financial Model 1. For "Indexed" Financial Model 1, there are two basic paths for analyzing the effects just cited (e.g., moving from the two-output, one input case, "Indexed" Financial Model 1, to the four-output, two-input case, "Indexed" Financial Model 16). The aim of the "Path Analysis" which follows is to gain a better understanding of what causes each MEC to move to the frontier.

Path 1 measures the differential effects by first adding outputs, then disaggregating one of the outputs, CMEPERID, into its component parts, and finally disaggregating the input NDX_TOT into its component parts. Path 2 measures the differential effects by first disaggregating the input NDX_TOT into its component parts, then adding outputs, and finally disaggregating one of the outputs, CMEPERID, into its component parts. Both Path 1 and Path 2 start with "Indexed" Financial Model 1 and end with "Indexed" Financial Model 16.

Taking each path in turn, we first describe the key characteristics of each path. We then examine the composition of the upper- and lower-quartile ranges, paying particular attention to changes (e.g., MECs entering the frontier, or MECs entering or leaving either the upper- or the lower-quartile ranges).

Table 4. 4 Summary of Key Results for Models Analyzed with DEA: Based on "Standard" Output Metric and Staff Input Metrics

Model	Upper-Quartile Range of 51 Centers		Lower-Quartile Range of 51 Centers
	Frontier Centers	Non Frontier Centers	
Staff Model 1	MEC40, MEC44	MEC39, MEC27, MEC33, MEC18, MEC09, MEC32, MEC48, MEC34, MEC19, MEC13, MEC02	MEC16, MEC20, MEC42, MEC22, MEC31, MEC30, MEC17, MEC15, MEC41, MEC37, MEC06, MEC10, MEC07
Staff Model 2	MEC04, MEC44	MEC40, MEC23, MEC26, MEC13, MEC14, MEC33, MEC09, MEC18, MEC51, MEC32, MEC01	MEC20, MEC31, MEC36, MEC16, MEC17, MEC15, MEC07, MEC29, MEC06, MEC41, MEC37, MEC30, MEC10
Staff Model 3	MEC04, MEC40	MEC39, MEC27, MEC23, MEC44, MEC18, MEC26, MEC13, MEC51, MEC14, MEC19, MEC01	MEC30, MEC20, MEC41, MEC49, MEC15, MEC45, MEC07, MEC22, MEC37, MEC10, MEC06, MEC12, MEC42
Staff Model 4	MEC27, MEC40	MEC39, MEC18, MEC36, MEC04, MEC05, MEC44, MEC19, MEC35, MEC33, MEC03, MEC13	MEC20, MEC21, MEC43, MEC30, MEC46, MEC37, MEC45, MEC49, MEC07, MEC10, MEC06, MEC12, MEC42
Staff Model 5	MEC09, MEC39, MEC40, MEC449	MEC27, MEC11, MEC48, MEC13, MEC34, MEC36, MEC33, MEC18, MEC32	MEC29, MEC20, MEC42, MEC06, MEC22, MEC31, MEC30, MEC17, MEC15, MEC41, MEC37, MEC10, MEC07
Staff Model 6	MEC04, MEC09, MEC44	MEC40, MEC23, MEC13, MEC26, MEC14, MEC48, MEC34, MEC11, MEC33, MEC51	MEC06, MEC42, MEC20, MEC22, MEC31, MEC17, MEC15, MEC29, MEC07, MEC30, MEC37, MEC41, MEC10
Staff Model 7	MEC04, MEC39, MEC40, MEC44	MEC27, MEC23, MEC18, MEC13, MEC14, MEC26, MEC36, MEC51, MEC09	MEC06, MEC31, MEC20, MEC41, MEC49, MEC45, MEC15, MEC22, MEC07, MEC37, MEC10, MEC12, MEC42
Staff Model 8	MEC18, MEC27, MEC36, MEC39, MEC40	MEC11, MEC09, MEC04, MEC05, MEC44, MEC19, MEC13, MEC16	MEC41, MEC02, MEC21, MEC46, MEC30, MEC06, MEC37, MEC45, MEC07, MEC49, MEC10, MEC12, MEC42
Staff Model 9	MEC04, MEC40, MEC44	MEC39, MEC23, MEC27, MEC26, MEC18, MEC13, MEC51, MEC14, MEC33, MEC09	MEC16, MEC20, MEC42, MEC17, MEC22, MEC31, MEC30, MEC15, MEC41, MEC07, MEC37, MEC06, MEC10
Staff Model 10	MEC27, MEC40, MEC44	MEC39, MEC18, MEC36, MEC33, MEC04, MEC09, MEC05, MEC32, MEC48, MEC34	MEC22, MEC15, MEC46, MEC41, MEC16, MEC20, MEC45, MEC42, MEC30, MEC37, MEC07, MEC10, MEC06
Staff Model 11	MEC04, MEC27, MEC40	MEC39, MEC18, MEC23, MEC44, MEC26, MEC51, MEC36, MEC05, MEC13, MEC14	MEC31, MEC20, MEC21, MEC30, MEC46, MEC37, MEC07, MEC45, MEC49, MEC10, MEC06, MEC12, MEC42
Staff Model 12	MEC04, MEC09, MEC39, MEC40, MEC44	MEC27, MEC23, MEC13, MEC26, MEC18, MEC14, MEC11, MEC48	MEC45, MEC29, MEC20, MEC06, MEC42, MEC22, MEC31, MEC30, MEC15, MEC41, MEC07, MEC37, MEC10
Staff Model 13	MEC09, MEC18, MEC27, MEC36, MEC39, MEC40, MEC44	MEC11, MEC48, MEC13, MEC34, MEC04, MEC33	MEC46, MEC20, MEC22, MEC45, MEC15, MEC31, MEC41, MEC06, MEC42, MEC30, MEC37, MEC07, MEC10
Staff Model 14	MEC04, MEC18, MEC27, MEC36, MEC39, MEC40, MEC44	MEC23, MEC26, MEC13, MEC11, MEC14, MEC09	MEC15, MEC41, MEC06, MEC21, MEC46, MEC30, MEC37, MEC45, MEC07, MEC49, MEC10, MEC12, MEC42
Staff Model 15	MEC04, MEC27, MEC40, MEC44	MEC39, MEC18, MEC23, MEC26, MEC13, MEC51, MEC36, MEC05, MEC14	MEC22, MEC15, MEC46, MEC41, MEC16, MEC20, MEC45, MEC42, MEC30, MEC37, MEC07, MEC10, MEC06
Staff Model 16	MEC04, MEC09, MEC18, MEC27, MEC36, MEC39, MEC40, MEC44	MEC23, MEC13, MEC26, MEC11, MEC14	MEC46, MEC20, MEC22, MEC45, MEC15, MEC06, MEC31, MEC41, MEC42, MEC30, MEC37, MEC07, MEC10

Table 4. 5 Summary of Key Results for Models Analyzed with DEA: Based on "Standard" Output Metrics and Financial Input Metrics

Model	Upper-Quartile Range of 51 Centers		Lower-Quartile Range of 51 Centers
	Frontier Centers	Non Frontier Centers	
Financial Model 1	MEC11	MEC37, MEC03, MEC33, MEC40, MEC19, MEC48, MEC27, MEC25, MEC39, MEC09, MEC04, MEC30	MEC05, MEC22, MEC17, MEC47, MEC24, MEC46, MEC20, MEC15, MEC10, MEC06, MEC43, MEC41, MEC07
Financial Model 2	MEC04, MEC11	MEC03, MEC33, MEC37, MEC23, MEC26, MEC48, MEC25, MEC40, MEC09, MEC14, MEC01	MEC24, MEC20, MEC46, MEC39, MEC43, MEC29, MEC15, MEC17, MEC06, MEC36, MEC10, MEC07, MEC41
Financial Model 3	MEC04, MEC11	MEC37, MEC40, MEC03, MEC23, MEC19, MEC27, MEC26, MEC39, MEC25, MEC51, MEC33	MEC45, MEC24, MEC46, MEC15, MEC20, MEC10, MEC22, MEC43, MEC41, MEC06, MEC07, MEC12, MEC42
Financial Model 4	MEC11, MEC37	MEC03, MEC40, MEC19, MEC27, MEC39, MEC25, MEC04, MEC33, MEC48, MEC18, MEC30	MEC49, MEC24, MEC45, MEC46, MEC20, MEC10, MEC47, MEC41, MEC43, MEC06, MEC07, MEC12, MEC42
Financial Model 5	MEC03, MEC09, MEC11, MEC37	MEC27, MEC25, MEC39, MEC40, MEC33, MEC19, MEC48, MEC18, MEC04	MEC05, MEC24, MEC17, MEC22, MEC47, MEC43, MEC20, MEC46, MEC15, MEC10, MEC06, MEC41, MEC07
Financial Model 6	MEC03, MEC04, MEC09, MEC11	MEC25, MEC37, MEC33, MEC23, MEC26, MEC48, MEC40, MEC01, MEC13	MEC24, MEC22, MEC31, MEC20, MEC46, MEC29, MEC15, MEC06, MEC17, MEC36, MEC10, MEC07, MEC41
Financial Model 7	MEC03, MEC04, MEC09, MEC11, MEC37	MEC27, MEC39, MEC25, MEC40, MEC23, MEC18, MEC19, MEC26	MEC49, MEC21, MEC45, MEC46, MEC15, MEC20, MEC10, MEC22, MEC41, MEC06, MEC07, MEC12, MEC42
Financial Model 8	MEC03, MEC09, MEC11, MEC27, MEC37	MEC39, MEC40, MEC19, MEC25, MEC40, MEC23, MEC18, MEC04	MEC43, MEC45, MEC24, MEC46, MEC49, MEC20, MEC10, MEC47, MEC41, MEC06, MEC07, MEC12, MEC42
Financial Model 9	MEC04, MEC11	MEC37, MEC03, MEC33, MEC40, MEC23, MEC19, MEC26, MEC48, MEC27, MEC25, MEC39	MEC47, MEC42, MEC12, MEC22, MEC24, MEC46, MEC20, MEC15, MEC10, MEC43, MEC06, MEC41, MEC07
Financial Model 10	MEC03, MEC11, MEC37	MEC33, MEC40, MEC48, MEC19, MEC25, MEC27, MEC09, MEC39, MEC04, MEC18	MEC47, MEC42, MEC12, MEC47, MEC24, MEC15, MEC20, MEC46, MEC10, MEC41, MEC06, MEC43, MEC07
Financial Model 11	MEC04, MEC11, MEC37	MEC03, MEC40, MEC19, MEC23, MEC27, MEC26, MEC33, MEC25, MEC39, MEC18	MEC47, MEC49, MEC21, MEC45, MEC20, MEC46, MEC41, MEC10, MEC43, MEC06, MEC07, MEC12, MEC42
Financial Model 12	MEC03, MEC04, MEC09, MEC11, MEC37	MEC27, MEC25, MEC39, MEC40, MEC33, MEC23, MEC18, MEC26	MEC17, MEC45, MEC31, MEC42, MEC24, MEC22, MEC20, MEC46, MEC15, MEC10, MEC06, MEC41, MEC07
Financial Model 13	MEC03, MEC09, MEC11, MEC27, MEC37	MEC39, MEC33, MEC25, MEC40, MEC48, MEC19, MEC18, MEC04	MEC31, MEC45, MEC42, MEC24, MEC47, MEC15, MEC43, MEC20, MEC46, MEC10, MEC41, MEC06, MEC07
Financial Model 14	MEC03, MEC04, MEC09, MEC11, MEC27, MEC37	MEC39, MEC25, MEC40, MEC23, MEC18, MEC19, MEC26	MEC22, MEC47, MEC21, MEC49, MEC45, MEC46, MEC20, MEC41, MEC10, MEC06, MEC07, MEC12, MEC42
Financial Model 15	MEC03, MEC04, MEC11, MEC37	MEC33, MEC40, MEC19, MEC48, MEC23, MEC25, MEC26, MEC27, MEC09	MEC47, MEC15, MEC24, MEC31, MEC42, MEC12, MEC20, MEC46, MEC41, MEC10, MEC43, MEC06, MEC07
Financial Model 16	MEC03, MEC04, MEC09, MEC11, MEC27, MEC37	MEC25, MEC39, MEC33, MEC40, MEC23, MEC18, MEC19	MEC47, MEC24, MEC22, MEC31, MEC45, MEC15, MEC42, MEC20, MEC46, MEC41, MEC10, MEC06, MEC07

Table 4. 6 Summary of Key Results for Models Analyzed with DEA: Based on "Standard" Output Metrics and "Indexed" Financial Input Metrics

Model	Upper-Quartile Range of 51 Centers		Lower-Quartile Range of 51 Centers
	Frontier Centers	Non Frontier Centers	
Financial "Indexed" 1	MEC11, MEC37	MEC03, MEC33, MEC40, MEC48, MEC27, MEC39, MEC19, MEC09, MEC30, MEC32, MEC25	MEC46, MEC47, MEC24, MEC20, MEC17, MEC05, MEC12, MEC10, MEC15, MEC06, MEC41, MEC43, MEC07
Financial "Indexed" 2	MEC04, MEC11	MEC26, MEC03, MEC33, MEC37, MEC23, MEC48, MEC40, MEC01, MEC32, MEC09, MEC14	MEC31, MEC39, MEC20, MEC29, MEC12, MEC17, MEC43, MEC06, MEC15, MEC36, MEC10, MEC41, MEC07
Financial "Indexed" 3	MEC04, MEC11, MEC37	MEC26, MEC23, MEC03, MEC40, MEC27, MEC19, MEC39, MEC30, MEC01, MEC33	MEC46, MEC49, MEC45, MEC20, MEC10, MEC41, MEC15, MEC22, MEC43, MEC06, MEC07, MEC12, MEC42
Financial "Indexed" 4	MEC11, MEC37	MEC03, MEC40, MEC27, MEC39, MEC19, MEC30, MEC33, MEC35, MEC26, MEC48, MEC04	MEC49, MEC14, MEC45, MEC10, MEC20, MEC15, MEC41, MEC47, MEC43, MEC06, MEC07, MEC12, MEC42
Financial "Indexed" 5	MEC03, MEC09, MEC11, MEC37	MEC33, MEC40, MEC39, MEC27, MEC48, MEC19, MEC25, MEC30, MEC18	MEC12, MEC47, MEC46, MEC22, MEC17, MEC20, MEC05, MEC43, MEC10, MEC15, MEC06, MEC41, MEC07
Financial "Indexed" 6	MEC03, MEC04, MEC09, MEC11, MEC26	MEC37, MEC23, MEC33, MEC48, MEC40, MEC25, MEC18, MEC01	MEC12, MEC22, MEC46, MEC20, MEC31, MEC29, MEC17, MEC06, MEC36, MEC15, MEC41, MEC10, MEC07
Financial "Indexed" 7	MEC03, MEC04, MEC09, MEC11, MEC37	MEC26, MEC23, MEC40, MEC27, MEC39, MEC18, MEC19, MEC25	MEC21, MEC46, MEC49, MEC45, MEC20, MEC41, MEC10, MEC22, MEC15, MEC06, MEC07, MEC12, MEC42
Financial "Indexed" 8	MEC03, MEC09, MEC11, MEC27, MEC37, MEC39	MEC40, MEC19, MEC18, MEC30, MEC33, MEC25, MEC35	MEC24, MEC14, MEC43, MEC49, MEC10, MEC20, MEC15, MEC41, MEC47, MEC06, MEC07, MEC12, MEC42
Financial "Indexed" 9	MEC04, MEC11, MEC37	MEC26, MEC03, MEC33, MEC23, MEC40, MEC48, MEC27, MEC19, MEC39, MEC01	MEC47, MEC31, MEC22, MEC46, MEC24, MEC20, MEC12, MEC10, MEC43, MEC41, MEC15, MEC06, MEC07
Financial "Indexed" 10	MEC03, MEC11, MEC37	MEC33, MEC40, MEC27, MEC48, MEC39, MEC19, MEC09, MEC30, MEC25, MEC32	MEC42, MEC22, MEC24, MEC47, MEC46, MEC20, MEC12, MEC10, MEC15, MEC41, MEC06, MEC43, MEC07
Financial "Indexed" 11	MEC04, MEC11, MEC37	MEC03, MEC26, MEC23, MEC40, MEC27, MEC19, MEC33, MEC39, MEC30, MEC18	MEC46, MEC49, MEC45, MEC15, MEC20, MEC22, MEC41, MEC10, MEC43, MEC06, MEC07, MEC12, MEC42
Financial "Indexed" 12	MEC03, MEC04, MEC09, MEC11, MEC26, MEC37	MEC23, MEC33, MEC40, MEC27, MEC39, MEC18, MEC48	MEC31, MEC43, MEC42, MEC17, MEC12, MEC46, MEC22, MEC20, MEC41, MEC10, MEC06, MEC15, MEC07
Financial "Indexed" 13	MEC03, MEC09, MEC11, MEC27, MEC37, MEC39	MEC33, MEC40, MEC48, MEC19, MEC25, MEC18, MEC30	MEC33, MEC46, MEC24, MEC12, MEC47, MEC46, MEC20, MEC43, MEC10, MEC15, MEC41, MEC06, MEC07
Financial "Indexed" 14	MEC03, MEC04, MEC09, MEC11, MEC26, MEC27, MEC37, MEC39	MEC23, MEC18, MEC40, MEC19, MEC33	MEC21, MEC46, MEC49, MEC22, MEC45, MEC20, MEC15, MEC41, MEC10, MEC06, MEC07, MEC12, MEC42
Financial "Indexed" 15	MEC03, MEC04, MEC11, MEC37	MEC26, MEC33, MEC23, MEC40, MEC27, MEC48, MEC19, MEC39, MEC01	MEC31, MEC24, MEC42, MEC22, MEC46, MEC20, MEC15, MEC41, MEC12, MEC10, MEC43, MEC06, MEC07
Financial "Indexed" 16	MEC03, MEC04, MEC09, MEC11, MEC26, MEC27, MEC37, MEC39	MEC23, MEC33, MEC18, MEC40, MEC48	MEC31, MEC43, MEC45, MEC42, MEC22, MEC12, MEC46, MEC20, MEC15, MEC41, MEC10, MEC06, MEC07

Path 1

Key Characteristics

Step 1:	"Indexed" Financial Model 1:	The basic two output, ACT_8 and CMEPERID, one input, NDX_TOT, case.
Step 2:	"Indexed" Financial Model 9:	Add C_PCTCME as the third output; maintain NDX_TOT as the single input.
Step 3:	"Indexed" Financial Model 15:	Disaggregate CMEPERID into its two component parts, CMEFIRST and C_CME_RP, thus creating a four output model; maintain NDX_TOT as the single input.
Step 4:	"Indexed" Financial Model 16:	Disaggregate NDX_TOT into its two component parts, NDX_PER and NDX_OPS; maintain the four outputs.

Composition of Upper-Quartile and Lower-Quartile

Step 1:	Frontier MECs:	MEC11, MEC37
	Non-Frontier MECs:	MEC03, MEC33, MEC40, MEC48, MEC27, MEC39, MEC19, MEC09 MEC30, MEC32, MEC25
	Lower-Quartile MECs:	MEC46, MEC47, MEC24, MEC20, MEC17, MEC05, MEC12, MEC10, MEC15, MEC06, MEC41, MEC43, MEC07
Step 2:	Frontier MECs:	MEC04 is added to the frontier
	Non-Frontier MECs:	MEC23 and MEC26 enter the upper-quartile range, MEC09, MEC30, and MEC32 move to the inter-quartile range, slight change in rankings
	Lower-Quartile MECs:	MEC17 and MEC05 move to the inter-quartile range, MEC22 and MEC31 enter the lower-quartile range, shift in rankings throughout the lower-quartile range

Step 3:	Frontier MECs:	MEC03 is added to the frontier
	Non-Frontier MECs:	No change in membership, slight change in rankings
	Lower-Quartile MECs:	MEC47 moves to the inter-quartile range, MEC42 enters the lower-quartile range, shift in rankings throughout the lower-quartile range
Step 4:	Frontier MECs:	MEC09, MEC26, MEC27, and MEC39 are added to the frontier
	Non-Frontier MECs:	MEC26, MEC27, and MEC39 move to the frontier, MEC18 enters the upper-quartile range, MEC01 and MEC19 move to the inter-quartile range
	Lower-Quartile MECs:	MEC43 moves to the inter-quartile range, MEC45 enters the lower-quartile range, shift in rankings throughout the lower-quartile range

Path 2

Key Characteristics

Step 1: "Indexed" Financial Model 1: The basic two output, ACT_8 and CMEPERID, one input, NDX_TOT, case.

Step 2: "Indexed" Financial Model 5: Disaggregate NDX_TOT into its two component parts, NDX_PER and NDX_OPS; maintain the two outputs.

Step 3: "Indexed" Financial Model 12: Add C_PCTCME as the third output; maintain the two inputs.

Step 4: "Indexed" Financial Model 16: Disaggregate CMEPERID into its two component parts, CMEFIRST and C_CME_RP, thus creating a four output model; maintain the two inputs.

Composition of Upper-Quartile and Lower-Quartile

Step 1:	Frontier MECs:	MEC11, MEC37
	Non-Frontier MECs:	MEC03, MEC33, MEC40, MEC48, MEC27, MEC39, MEC19, MEC09, MEC30, MEC32, MEC25
	Lower-Quartile MECs:	MEC46, MEC47, MEC24, MEC20, MEC17, MEC05, MEC12, MEC10, MEC15, MEC06, MEC41, MEC43, MEC07
Step 2:	Frontier MECs:	MEC03 and MEC09 are added to the frontier
	Non-Frontier MECs:	MEC03 and MEC09 move to the frontier, MEC18 enters the upper-quartile range, MEC32 moves to the inter-quartile range, slight change in rankings
	Lower-Quartile MECs:	MEC24 moves to the inter-quartile range, MEC22 enters the lower-quartile range, shift in rankings throughout the lower-quartile range
Step 3:	Frontier MECs:	MEC04 and MEC26 are added to the frontier
	Non-Frontier MECs:	MEC23 enters the upper-quartile range, MEC19, MEC25, and MEC30 move to the inter-quartile range, shift in rankings throughout the upper-quartile range
	Lower-Quartile MECs:	MEC05 moves to the inter-quartile range, MEC42 enters the lower-quartile range, shift in rankings throughout the lower-quartile range
Step 4:	Frontier MECs:	MEC27 and MEC39 are added to the frontier
	Non-Frontier MECs:	MEC27 and MEC39 move to the frontier, slight change in rankings
	Lower-Quartile MECs:	MEC17 moves to the inter-quartile range, MEC45 enters the lower-quartile range, shift in rankings throughout the lower-quartile range

4.3. Interpretation of Selected Results

The previous section has covered a great deal of material. Consequently, it is helpful to pause and pull together our findings. We begin with a synopsis of the two paths described in the text of Section 4.2. The two paths are summarized graphically in Figure 4.1. The figure provides a schematic diagram of a step-by-step analysis associated with a typical cross-model comparison process. The figure traces each step, going from left (i.e., the Step 1, two-output, one-input model) to right (i.e., the Step 4, four-output, two-input model). The figure also helps us to interpret the results of our DEA analyses.

In interpreting the results of our analyses, we shall focus on those MECs which defined the production frontier. First, we see that two MECs--MEC11 and MEC37--are on the frontier for "Indexed" Financial Model 1. Second, there are eight MECs on the frontier for "Indexed" Financial Model 16; namely, the two originals plus MEC03, MEC04, MEC09, MEC26, MEC27, and MEC39. Next, we examine the six MECs which are ultimately added to the frontier. Our aim is to gain a better understanding of what is causing them to be frontier centers. This understanding can be used to encourage benchmarking among MECs by linking specific areas of excellence for a reference center with the corresponding opportunities for improvement for one or more of its non-frontier MECs.

We begin with Path 2, shown in the lower portion of Figure 4.1. Two MECs, MEC03 and MEC09, enter the frontier when NDX_TOT is disaggregated. This result is telling us that when you consider the financial input as an aggregated total, the performance of these MECs is not exemplary. One reason why these MECs might move to the frontier is that they excel in the allocation of their financial resources among staff and operating expenses. If this is the case, MEC03 and MEC09, represent excellent benchmarking opportunities for their "associated" non-frontier MECs. However, a closer examination of the data revealed that this "desired" outcome was not the case. The two MECs in question did not excel at "diversifying" or "balancing" their financial resources among staff and operating expenses. Rather they excelled through "specialization" in one or the other. This outcome raises a question on the merits of disaggregating the financial input. If seeking an "ideal" balance is desired, then disaggregating the financial input in DEA analyses only helps to identify a potential set of "best practice" MECs. Once the DEA analyses have been performed and the "paths" analyzed, it becomes necessary to review each of the MECs which were initially on the frontier (i.e., when the financial input was aggregated) and each MEC added to the frontier whenever the financial input is disaggregated. Such follow-up analyses could include scatter plots, or similar graphics-oriented tools, to differentiate cases where specialization prevails from those in which diversification prevails. In principle, a template could be designed which identifies those cases which arise out of "diversification" and out of "specialization."

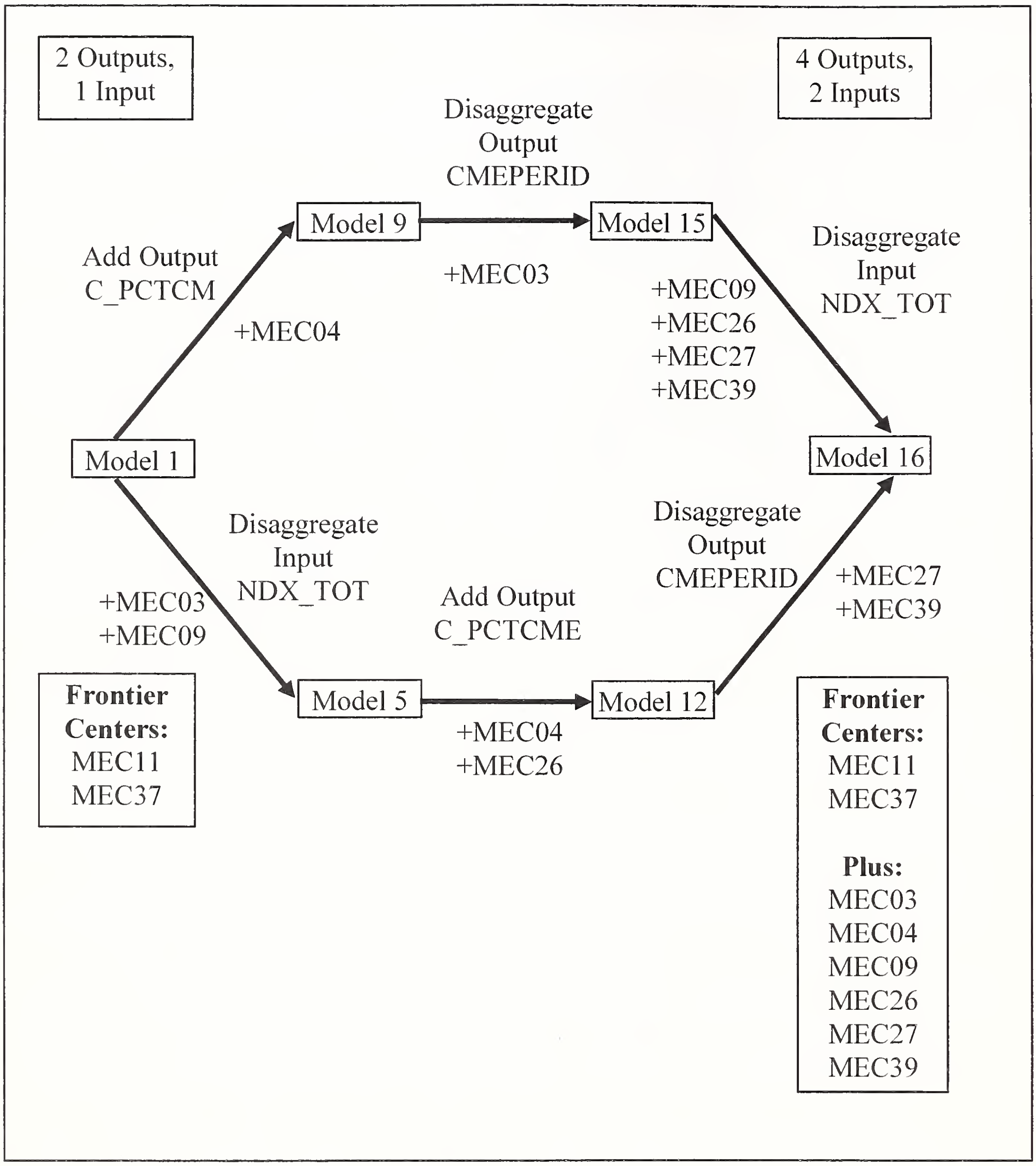

Figure 4. 1 Measuring the Effects of Changing the Outputs and Inputs on the Production Frontier

Two MECs, MEC04 and MEC26, are added to the frontier when the output C_PCTCME is added. Thus one could conclude that these MECs are doing very well in covering their target population of CMEs. A review of the operating data set revealed that MEC04 and MEC26 were in the upper-quartile for the reported coverage's among the 51 MECs analyzed. It is worth noting that the two MECs with the highest reported coverage's, MEC19 and MEC40, *were not added to the frontier*. The fact that the two MECs with the highest reported coverage's are not on the frontier highlights an important strength of DEA, namely that it provides better insights into relative performance whenever multiple inputs and outputs come into play.

Next, consider the two MECs, MEC27 and MEC39. These MECs exhibit an interesting pattern of performance. For Path 2, these MECs enter the frontier when the output CMEPERID is disaggregated; for Path 1, they enter the frontier when the input NDX_TOT is disaggregated. To interpret this outcome, it is helpful to assess whether one effect dominates or if they are of equal importance. We shall begin by referring once again to Table 4.6. The table reveals that MEC27 and MEC39 are on the frontier whenever *both* CMEPERID *and* NDX_TOT *are disaggregated* (i.e., "Indexed" Financial Models 8, 13, 14, and 16). Therefore, the effects are of equal importance.

Finally, consider MEC09 and MEC26. For Path 1, they enter the frontier when the input NDX_TOT is disaggregated. For Path 2, MEC09 enters the frontier when NDX_TOT is disaggregated, while MEC26 enters the frontier when the output metric C_PCTCME is added. Once again we assess whether one effect dominates or if they are of equal importance. Reference to Table 4.6 reveals that MEC09 is on the frontier whenever NDX_TOT is disaggregated, implying that disaggregating the input is the effect which dominates. In the case of MEC26, it is on the frontier only when three characteristics are present simultaneously in the model: (1) ACT_8; (2) C_PCTCME; and (3) NDX_TOT is disaggregated. These characteristics are present in "Indexed" Financial Models 6, 12, 14, and 16, implying that the effects are of equal importance.

Interpreting the results of DEA analyses, such as cross-model comparisons, helps to sharpen benchmarking opportunities among frontier and non-frontier MECs (e.g., by focusing on those effects which caused a particular MEC to move to the frontier). In addition, the interpretations built around Figure 4.1 and the two path descriptions given in Section 4.2 raise important questions which point to other areas for analysis. These areas include whether some form of stratification within a particular data set is necessary.

Consider the two paths which formed the basis for our cross-model comparisons of the "indexed" financial models. Both paths lead to the same types of questions which argue for further analysis; namely, the shifts in rankings due to: (1) disaggregating CMEPERID into its two component parts; and (2) disaggregating NDX_TOT into its two component parts. The grouping of the models enables us to examine these shifts in several ways. For Path 1, we can examine the changes between Step 2 and Step 3 for the first case and between Step 3 and Step 4 for the second case. For Path 2, we can examine the changes

between Step 3 and Step 4 for the first case and between Step 1 and Step 2 for the second case. In the first case, we are looking for how the relative mix between first time and repeat service to CMEs affects the ranking. Types of analyses might include a scatter plot of the raw data followed by a series of scaling operations (e.g., ratios of each component to the whole), with follow-up analyses aimed at whether the MEC was new or well-established. In the second case, we are looking at the relative efficiency of how (administrative and field) staff and operations resources are utilized. In addition to the types of analyses suggested for the previous case, evaluating how MECs in high-cost areas compare to those in low-cost areas would be particularly valuable. Although the "indexed" financial models represent an important step in this direction, the results documented in Figure 4.1 demonstrate that probing for deeper meaning is essential if focused benchmarking activities among MEC are to take place. Finally, the types of analyses just described will provide insights on the pros and cons of data stratification.

5. Summary, Conclusions, and Suggestions for Further Research

5.1. Summary

The purpose of this report is threefold. First, it describes how DEA could be applied to assist the MEP Program and its network of MECs measure and evaluate their performance. For example, the following key concepts are described:

- how the performance frontier enables us to calculate the efficiency of a given set of MECs;

- how to identify MECs which can serve as reference centers (i.e., suggest paths to improve) for other, less efficient MECs; and

- how to use index measures to assess the success of the overall MEP Program in "pushing" the performance frontier outwards.

Second, it uses data from the current NIST/MEP Management Information Reporting System to illustrate ways in which DEA can help MEP headquarters and its network of MECs to measure their performance. Specific results from DEA analyses of this MEC operating data set include:

- specification of a series of models based on a unique combination of key inputs--staff and financial resources--and outputs; in all, 48 models were evaluated;

- specification of efficiency ranges and identification of reference centers for each of the three "most-detailed" models evaluated;

- identification of the frontier MECs, non-frontier MECs in the upper-quartile range, and MECs in the lower-quartile range for each of 48 models evaluated; and

- cross-model comparisons illustrating how to measure the differential effects of adding a new variable or disaggregating an existing variable.

Finally, this report seeks to stimulate feedback and discussion among those engaged in MEP performance assessment. DEA provides a method which MEP and its network of MECs can use jointly to make sense of the multi-dimensional nature of MEC performance data. While DEA is only one of several MEP approaches to performance assessment, it is a particularly flexible and interactive one. With this report MEP is in a position to initiate further uses of DEA which will prove beneficial to both the MECs and the national program.

5.2. Conclusions

This research was motivated by the MEP Program's twin needs to both measure performance and identify specific actions to improve performance. This report demonstrates how DEA meets these twin needs. In addition, the material presented in this report leads to five, fairly specific, conclusions which should facilitate the use of DEA as an analytical tool for the MEP Program.

First, the feasibility of DEA has been demonstrated with actual MEP data. This conclusion is particularly important because the MEP Program has an extensive set of data on each MEC. In particular, the Semi-Annual Report, which is submitted by each MEC to the MEP Program headquarters at NIST, provides a wealth of information for DEA applications. Consequently, no new data collection/data development effort is required in order to implement DEA as an analytical tool.

Second, DEA permits each MEC's performance to be measured in an objective, consistent manner. Specifically, each MEC is evaluated against all other MECs using the same set of input and output variables. Thus, each MEC's performance is measured relative to "actual achieved" levels of performance of other MECs, rather than to some theoretical optimum. In addition, DEA is sufficiently flexible to adjust for systematic differences among MECs. For example, cost differences between MECs operating in high cost areas and those operating in low cost areas can be normalized via a cost index. Similarly, differences between newly-established MECs and those which have been in existence for several years can be analyzed by comparing the relative importance of first time service to CMEs versus repeat business. Finally, by using "personalized" weights to uniquely combine each MEC's inputs and outputs so as to maximize its performance, DEA presents each MEC in its "most favorable light."

Third, the form of the model used in the DEA analyses provides insights into MEC performance. This is because different model formulations measure different types of results. MECs which are on the frontier for one model formulation are not necessarily on the frontier for another. Similarly, MECs which are in the upper-quartile range for one model formulation may either move to the frontier, stay in the upper quartile, or move to another quartile for a different model. Cross-model comparisons and "path analyses" employ different model formulations to provide insights both into areas of relative strengths and opportunities for improvement. In particular, cross-model comparisons and "path analyses" provide the means for identifying which MECs have moved to the frontier and why.

Fourth, DEA produces a well-defined set of reference centers for each non-frontier MEC. Reference centers are a core concept of DEA, since they provide the basis for benchmarking among MECs. These "benchmarking opportunities" enable specific "areas of excellence" to be identified and used to drive performance improvement for non-frontier MECs. Additional work, outlined in the next section, will provide a framework for stimulating benchmarking activities among MECs.

Fifth, DEA provides a mechanism for measuring the performance of the overall MEP Program. This mechanism, outlined in the next section, shows how a time series of DEA analyses may be used to establish a set of "rolling benchmarks" for the MEP Program itself.

5.3. Suggestions for Further Research

As the MEP Program takes steps to employ DEA as a performance improvement tool, it is suggested that it expand its efforts in the following areas. These areas are designed to provide the MEP Program with a suite of products which support the measurement and evaluation of both individual MECs and the overall national program's efforts. Four specific products are proposed.

5.3.1. Selection of Variables and Models: Towards a "Standard" Set of Variables and Models

The results presented in Chapter 4 demonstrate how a carefully chosen set of models can be used to examine the effects that introducing/disaggregating outputs and inputs have on MEC performance. If a "standard" set of variables and models were developed, it would enable MEP to evaluate performance on at least two fronts. First, it enables MEP headquarters to suggest benchmarking opportunities between MECs. Second, it enables MEP to evaluate its success in pushing the performance frontier outward, creating a dynamic, as opposed to static, improvement process.

A key component in the development of a standard set of variables and models, is a critical analysis of the pros and cons of the two following issues: (1) disaggregating the staff and financial inputs; and (2) data stratification. Results presented in Section 4.3 showed that disaggregating the financial input can produce frontier MECs which specialize in one of the two financial inputs (i.e., either staff or operating expenses). Additional research and analysis is needed on this issue to determine if specialization is a "best practice" which other MECs should emulate. Additional research is needed on the data stratification issue to determine if some alternative grouping of MECs would yield results which lead to better benchmarking opportunities.

As the MEP Program moves toward establishing a standard set of variables and models for DEA analyses, it should work to capture information on the following two types of variables. First, additional work is needed to further refine and apply methods of controlling for variations in costs due to geographical dispersion among MECs. Second, priority should be placed on expanding the capability to utilize information from additional sources (e.g., the NIST/MEP Short Term Follow-Up Survey Data) as DEA output variables. A key advantage of this approach is its focus on "outcomes-oriented" metrics. Another advantage is the potential for creating linkages between REMI[10]

[10] Treyz, G. I., Rickman, D. S., and Shao, G. 1992. "The REMI Economic-Demographic Forecasting and Simulation Model," *International Regional Science Review*, **Vol. 14**, pp. 221-253.

(Regional Economic Models, Inc.) and DEA analyses. REMI is a tool being used by the Office of Applied Economics to measure the economic impacts of government technology programs[11].

5.3.2. Feedback Reports for Individual Centers

Once a standard set of DEA variables and models has been specified, it becomes possible to initiate a more focused effort at continuous improvement. Feedback reports to each MEC are one means for focusing an MEC's attention on both its strengths and improvement opportunities. Ideally, the design of the feedback report would be built around a template for reporting key results. The MEP Program already has templates which all MECs use in completing their Monthly and Semi-Annual Reports. While templates are widely used by MECs, work is needed to design the DEA template to insure that the DEA-related results which are recorded on it are provided in a form which the MEC can easily understand and act upon. The feedback report, in the form of a template, thus represents an important step towards identifying benchmarking opportunities between a non-frontier MEC and its reference centers.

5.3.3. Process for Benchmarking Among Centers

The reference center concept identifies benchmarking opportunities for non-frontier MECs. In order to ensure that the benchmarking opportunities become a "two-way street" to performance improvement, a process for benchmarking among MECs needs to be developed and tested.

Because DEA has been widely used in geographically distributed settings similar to those faced by MEP, much can be learned from the literature on the subject and through discussions with practitioners and veterans in the field. Our goal is to produce a process which is clear and simple but robust enough to produce results.

5.3.4. Process for Measuring the Performance of the MEP Program

If a standard set of variables and models is established, then an important aspect of overall MEP Program performance can be measured through an index. The index uses a time series of the optimally-calculated weights from DEA (i.e., a set of weights for each frontier center at different points in the time series) to determine if the performance frontier is being pushed outward. From the overall MEP Program perspective, pushing the performance frontier outward is a desired outcome because it implies greater "absolute" efficiency.

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[11] Ehlen, Mark A., and Weber, Stephen F. 1997. *Estimating Economic Impacts of Government Technology Programs: Manufacturing Studies Using the REMI Model.* NISTIR 6107. Gaithersburg, MD: National Institute of Standards and Technology.

Appendix A. A Graphical Approach to Performance Assessment

The purpose of this appendix is to present a graphical approach to performance assessment which illustrates two key DEA concepts. First, the appendix describes how the efficiency of a non-frontier MEC is calculated. Second, using a graphical representation of efficiency, a set of optimal weights is derived. Data on three MECs are used to illustrate how the graphical approach would be applied in practice.

Consider the case of Staff Model 1. This two output, one-input model had ACT_8 and CMEPERID as outputs and FTETOTAL as the input. For our purposes here, we shall denote ACT_8 as output 1, O_1, and CMEPERID as output 2, O_2, respectively. We denote the single input, FTETOTAL as I.

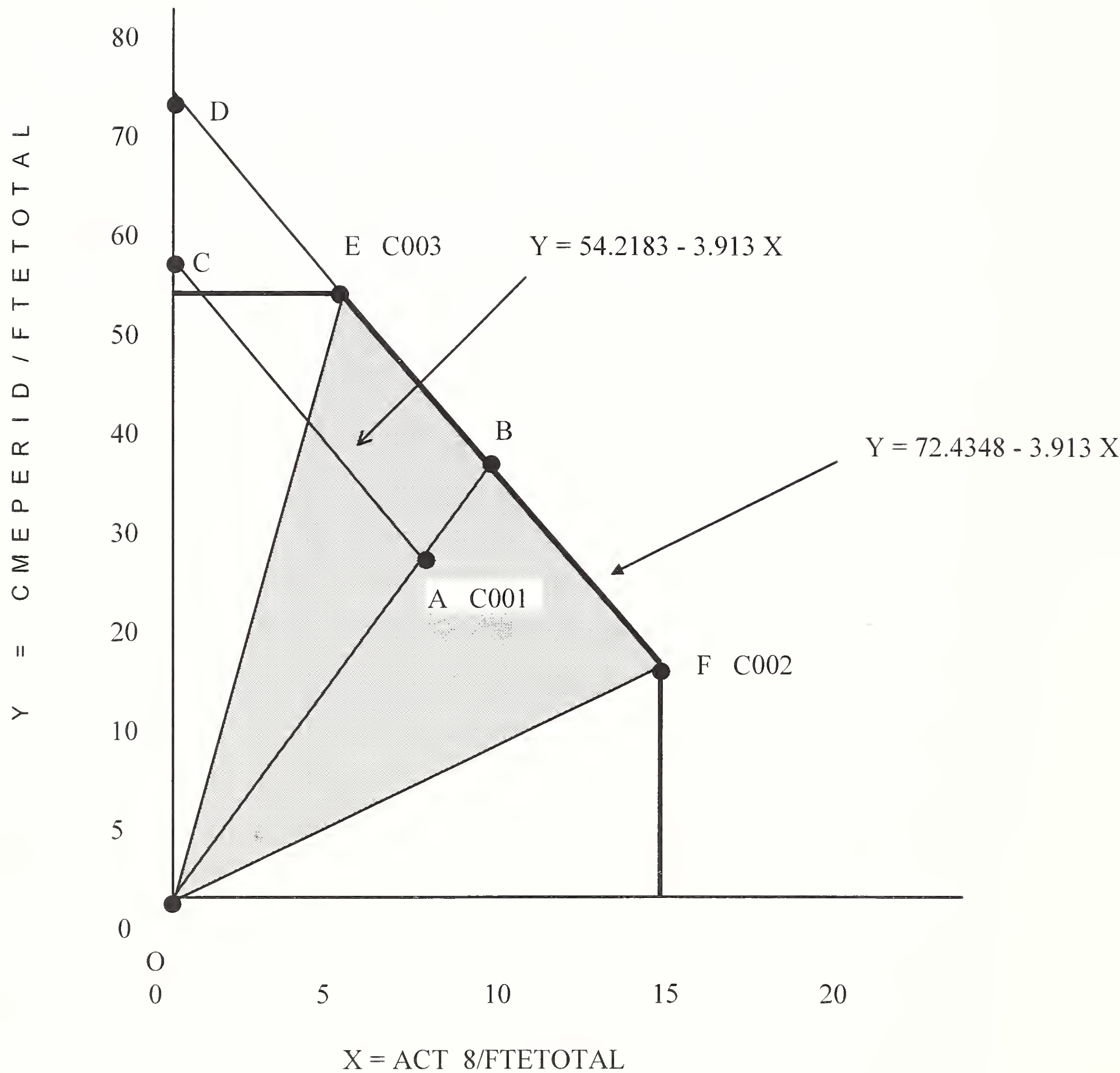
Figure A.1 plots the results of Staff Model 1 for three MECs, C002, C003, and C001. Two of these MECs, C002 and C003, are frontier MECs. The third MEC, C001, is a non-frontier MEC. In developing Figure A.1, the ratio O_1 of over I, is designated as X and the ratio of O_2 over I is designated as Y. This allows us to use the convenient geometric representation of the XY-axis, where X is the horizontal axis and Y is the vertical axis. The values used to construct Figure A.1 are summarized in Table A.1.

Table A.1 Summary of Key MEC Operating Data

MEC	ACT_8	CMEPERID	FTETOTAL	O_1/I	O_2/I
ID	O_1	O_2	I	X	Y
C001	333	1191	46	7.2391	25.8913
C002	188	206	13	14.4615	15.8462
C003	47	468	9	5.2222	52.0000

Refer now to Figure A.1. For C001, plotted as point A on the figure, both C003, plotted as point E, and C002, plotted as point F, serve as reference centers. In addition, we can identify a target point, B, on the frontier which represents the C001 MEC's potential. In the case of the C001 MEC, the target point is B on the frontier and C001's efficiency is given by the ratio OA/OB. Simple geometry establishes that the ratio OA/OB is the same as the ratio OC/OD. The point D is given by the line BD obtained by extending the line joining C003 and C002 to the Y-axis. The point C is given by the intercept on the Y-axis of the line AC drawn parallel to BD through the point A (i.e., C001).

Figure A.1 Efficiency Calculations for the C001 MEC



The equation of the line BD is

$$Y = 72.4348 - 3.913 * X \qquad \text{Eq.A.1}$$

where Y is CMEPERID/FTETOTAL (i.e., O_2/I), X is ACT_8/FTETOTAL (i.e., O_1/I), -3.913 is the slope of the line,[12] and 72.4348 is the value of the intercept of the line on the Y-axis (OD). The equation of the line AC is

$$Y = 54.2183 - 3.913 * X \qquad \text{Eq.A.2}$$

where 54.2183 is the value of the intercept of the line on the Y-axis (OC). Hence, our measure of C001's efficiency is given by

$$\frac{OA}{OB} = \frac{OC}{OD} = \frac{54.2183}{72.4348} = 0.7485 \qquad \text{Eq.A.3}$$

Let us explore equations A.1 and A.2 further. For the purpose of generalization, let us denote the coordinates of the three MECs, C001, C002, and C003, as (X(C001), Y(C001)), (X(C002), Y(C002)), and (X(C003), Y(C003)), respectively. Then, by substitution we have

$$OC = 54.2183 = Y(C001) + 3.913 * X(C001) \qquad \text{Eq.A.4}$$

$$OD = 72.4348 = Y(C002) + 3.913 * X(C002) \qquad \text{Eq.A.5}$$

$$OD = 72.4348 = Y(C003) + 3.913 * X(C003) \qquad \text{Eq.A.6}$$

Dividing all three equations by OD (=72.4348) and switching the left and right hand sides of the equations gives us

$$0.0138 * Y(C001) + 0.054 * X(C001) = 0.7485 \qquad \text{Eq.A.7}$$

$$0.0138 * Y(C002) + 0.054 * X(C002) = 1 \qquad \text{Eq.A.8}$$

[12] The slope of the line is equal to [(Y(C003) - Y(C002)) / (X(C003) - (X(C002))] or, in numeric terms, (52.0000 - 15.8462) / (5.2222 - 14.4615).

$$0.0138 * Y(C003) + 0.054 * X(C003) = 1 \qquad \text{Eq.A.9}$$

We originally obtained the X and Y values by dividing each MEC's outputs by its input. Let us define $O_1(C001)$ and $O_2(C001)$ to be the C001 MEC's outputs and I(C001) to be its input and assume similar notation for the frontier MECs, C002 and C003, respectively. Hence we have

$$Y\,(C001) = \frac{O_2(C001)}{I(C001)} \qquad \text{Eq.A.10}$$

$$X\,(C001) = \frac{O_1(C001)}{I(C001)} \qquad \text{Eq.A.11}$$

Similar relationships exist for the C002 and C003 MECs. Substituting Eq. A.10 and A.11 into Eq. A.7 through A.9 gives

$$\frac{0.0138 * O_2(C001) + 0.054 * O_1(C001)}{I(C001)} = 0.7485 \qquad \text{Eq.A.12}$$

$$\frac{0.0138 * O_2(C002) + 0.054 * O_1(C002)}{I(C002)} = 1 \qquad \text{Eq.A.13}$$

$$\frac{0.0138 * O_2(C003) + 0.054 * O_1(C003)}{I(C003)} = 1 \qquad \text{Eq.A.14}$$

Finally, we can constrain the denominator of equation A.12 to be equal to a value of 1 by dividing both the numerator and denominator of equation A.12 by the value of I(C001) (i.e., 46, see Table A.1). We repeat the same step (i.e., dividing the numerator and denominator by 46) for equations A.13 and A.14. This gives

$$\frac{0.0003 * O_2(C001) + 0.0017 * O_1(C001)}{0.02174 * I(C001)} = 0.7485 \qquad \text{Eq.A.15}$$

$$\frac{0.0003 * O_2(C002) + 0.00117 * O_1(C002)}{0.02174 * I(C002)} = 1 \qquad \text{Eq.A.16}$$

$$\frac{0.0003 * O_2(C003) + 0.00117 * O_1(C003)}{0.02174 * I(C003)} = 1 \qquad \text{Eq.A.17}$$

The purpose of this constraint is to accord with the solution procedure outlined in Section 2.3.

Thus, we have expressed our efficiency measure for the C001 MEC (0.7485) as the ratio of the weighted sum of its outputs to the weighted sum of its input while restricting the value of the weighted sum of its input to 1. Furthermore, the value of the weighted sum ratio obtained using the same weights for either of C001's reference MECs, C002 and C003, is 1 (refer to equations A.16 and A.17).

Also, since all of the inputs and outputs have positive values, it is clear by direct inspection of the ratios (i.e., equations A.15, A.16, and A.17) that, if we increase either of the output weights or decrease the input weight in order to increase the computed efficiency for C001, then an identical change to either the C002 or C003 ratio will cause it to exceed the value 1. Hence, the weights obtained maximize the value of a weighted sum ratio, subject to the constraint that the same weighted ratio of any other MEC's outputs to inputs must not exceed the value 1.

In summary, we have demonstrated that our graphical efficiency measure for the C001 MEC obtained from Figure A.1 is equivalent to the value of the ratio of a weighted sum of its outputs and a weighted sum of its input, *where the weights are selected to maximize the value of the ratio* subject to the value of the same weighted ratio of any other MEC's outputs and inputs not exceeding 1. Let us now consider further how the weights should be interpreted. If we return to equations A.4, A.5 and A.6, we see that the coefficients of Y and X in each case are 1 and 3.913, where the latter is the negative of the slope of the line BD. In the subsequent development to generate the ratio of weighted sums, the output weights were maintained in this proportion. In other words, the ratio of the output weights is equal to the slope of the line on the frontier which contains the point against which efficiency is measured. This slope represents the trade-off between the two outputs at that point.

Note that any other MEC within the shaded triangle OEF would also be measured with respect to a point on the line segment EF. Hence a further consequence of the above result is that all MECs in the triangle have output weights in the same proportion. Finally, if there were another MEC within the triangle OEF and also on the line AC, the equations for this MEC would be identical to those for C001, resulting in an identical efficiency score being achieved. Hence efficiency contours exist and are parallel to the frontier.

It is critical to recognize that the weights represent the trade-offs which apply across a frontier segment. However, by virtue of the fact that these weights maximize the weighted sum ratio of outputs to inputs within the constraints imposed, we can be certain that no other MEC will ever be presented in a better light by an alternative method of weighting. Equivalently, we can be certain that DEA will never overestimate improvement potential relative to that identified by any other weighting method. Thus, the weights for each MEC are ***uniquely determined so as to maximize its efficiency*** subject to the constraint that no other MEC can have an efficiency greater than 1 with the same weights.

Appendix B. Mathematical Formulation

Consider the one-input, two-output, problem discussed in Appendix A. The efficiency of each MEC on the frontier was defined as being equal to 1.0. Additionally, the efficiency of the MEC not on the frontier was calculated as the ratio of two radial distances defined by its plotted performance.

Norman and Stoker have shown that this graphical approach to calculating efficiencies is equivalent to calculating efficiencies as the ratio of the weighted sum of the MEC's outputs divided by the weighted sum of its inputs, where each MEC's weights must satisfy two sets of constraints. First, the weights are all constrained to be non-negative. Second, the weights for each MEC are chosen to maximize its calculated efficiency, subject to the restriction that neither its nor any other MEC's efficiency using these same weights exceed 1.0.

This problem statement can be generalized to the case with $\boldsymbol{O}$ outputs and $\boldsymbol{I}$ inputs. Denoting the inputs and outputs of the $\boldsymbol{k}$th MEC as

inputs: x_{ik}, $i = 1, \ldots, I$

outputs: y_{jk}, $j = 1, \ldots, O$

the problem can be stated as follows, where N is the number of MECs included in the analysis:

$$\max e_k = \frac{\sum_{j=1}^{O} w_j y_{jk}}{\sum_{i=1}^{I} v_i x_{ik}}$$

subject to:

$$\frac{\sum_{j=1}^{O} w_j y_{jm}}{\sum_{i=1}^{I} v_i x_{im}} \le 1; \qquad m = 1, \ldots, N$$

$$w_j \ge 0; \qquad j = 1, \ldots, O$$

$$v_i \ge 0; \qquad i = 1, \ldots, I$$

The definition above is not a linear programming problem because the objective function is not a linear function of the inputs. In their landmark paper which introduced the DEA method, Charnes, Cooper and Rhodes[13] introduced the following formulation as a re-statement of this problem in linear programming terms:

[13] Charnes, A., Cooper, W., and Rhodes, E. 1978. "Measuring the Efficiency of Decision Making Units." *European Journal of Operational Research.* **Vol. 2**, pp. 429-444.

$$\max\ e_k = \sum_{j=1}^{O} w_j y_{jk}$$

subject to:

$$\sum_{i=1}^{I} v_i x_{im} - \sum_{j=1}^{O} w_j y_{jm} \geq 0; \quad m = 1, \ldots, N$$

$$\sum_{i=1}^{I} v_i x_{ik} = 1$$

$$w_j \geq 0; \quad j = 1, \ldots, O$$

$$v_i \geq 0; \quad i = 1, \ldots, I$$

When solving the linear programming problem for the ***k***th MEC, the input weights are selected so that the weighted sum of the inputs equals 1.0. The output weights are selected to maximize the weighted sum of the outputs, and thus the efficiency of the ***k***th MEC. Thus, weights are selected which show each MEC in the best possible light. Does this mean that all MECs are found to be 100% efficient? No, because the first of the four restriction equations listed above requires that *no other MEC* be found more than 100% efficient using those same input and output weights with its own levels of inputs and outputs.

Note that this linear programming problem is solved for the ***k***th MEC. Thus, ***n*** of these separate linear programming problems must be solved to generate the full set of efficiency scores.

Any linear programming problem has an equivalent "dual" linear programming problem whose solution is mathematically equivalent to the original or "primal" formulation.[14] The dual formulation is crucial in the application of DEA, since it is the vehicle through which the ***k***th MEC's reference centers are identified. The identification of reference centers is accomplished through a post-processing operation which examines the values of the dual variables associated with each constraint in the original or primal formulation. Non-zero values of the dual variables imply that the constraint is binding (i.e., the efficiency of the ***k***th MEC would be higher if that constraint were relaxed). Those constraints which are binding for the ***k***th MEC taken together define a "facet" on the performance frontier. The vertices of the facet correspond to the ***k***th MEC's reference centers. Thus, to form the set of reference centers for the ***k***th MEC, it is sufficient to examine the *N* MEC-related constraints and identify which MECs are associated with the constraints which are binding (i.e., whose dual variables have non-zero values).

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[14] See, for example, Gass, Saul I. 1985. *Linear Programming.* Fifth Edition. New York: McGraw-Hill Book Company

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